Christian Hülsmeyer and the early days of radar, a survey
Part II

Introduction

There exist many publications on the subject of who may have invented radar. The course of history of this aspect of technology, might very well have been very different when we consider what one **could** and, in my opinion, **should** have been known, from the status of patents and comparable accessible literature.

We have seen, in the previous chapter, that Hülsmeyer's radar related German patent applications of 1904 described nearly all standard features of modern radar apparatus.[1] Britain was very well informed on this subject, as several magazines had published all sorts of abstracts on Hülsmeyer's electrical inventions.[2]

I have chosen, mainly to follow the patent literature as this may be regarded as being an open source for industrial and scientific evolution. Consequently, I have omitted the less promising third hand stories on "detecting objects at distance by means of acoustical waves and/or low frequency electrical waves".[3]

The state of affairs from the early 1920s

First let us consider what Marconi said during his speech to the American Institute of Radio Engineers in New York in June 1922[4]:

"It seems to me that it should be possible to design apparatus by means of which a ship could radiate or project a divergent beam of rays in any desired direction which rays, if coming across a metallic object such as another steamer or ship would be reflected back to a receiver screened from the local transmitter on the sending ship and thereby reveal the presence of the other ship in fog or thick weather. One further advantage of such an arrangement would be that it would be able to give warning of presence and bearing of ships even should these ships be unprovided with any kind of radio".

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[1] DE165546 filed on 30 April 1904 and DE169154 filed on 11 November 1904

[2] (Neglecting the patent specifications of GB13170/1904 and GB25608/1904). For instance: IEE Science Abstracts, section B- Electrical Engineering, 1905/1906. "The Telemobiloscope", The Electrical Magazine (London) Vol 2, 1904, p.388

[3] Such as by: L. Richardson pulsed beam of acoustic radiation of frequency from 5 kHz to 100 kHz. C.V. Drysdale and Fessenden [Burns, p.8-9]

[4] Cited from V.J. Phillips'article in Wireless World of July 1978, called: The Telemobiloscope an Edwardian radar, p.68

Notwithstanding that nothing was done about Marconi's reflections for a decade to come, its content is nearly similar to that of which Hülsmeyer had expressed, about eighteen years earlier, during the presentation of his apparatus for technical experts of major trans-Atlantic shipping companies on 9th June 1904, in the harbour of Rotterdam.

Heinrich Löwy's "electromagnetic" commitments

The first serious scientific approach to using EM waves for detecting conducting objects (such as water and metallic (geological) layers) was granted in a patent in the names of Gotthelf Leimbach and Heinrich Löwy, be it that they suggested its use it for geological purposes.[5] Vertical holes of several hundred metres had to be drilled into the ground of which one in the middle was fitted with a transmitting antenna system and the other holes had to be fitted with receiving antenna systems. By comparing the magnitude of the received signals, one may discover what the contents of the sub surface layers are. This technology is still in use today and is known as "borehole radar".[6]

The next year Dr. Löwy himself applied for a patent, which used more sophisticated technology.[7] He suggested utilizing a transmitting source S and a receiving arrangement E. To determine the distance between the plane of the (S-E) and the reflecting layer (strata), he suggested varying the frequency, and meanwhile observing the resulting maximum and minimum field strength patterns, resulting from the interference between the surface and sub-surface EM waves.[8]

In the early 1920s Telefunken applied for a patent by which means they suggested the use of EM waves for detecting sub-surface conducting objects.[9] One paragraph is of some interest,

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[5] DE237944 filed on 15 June 1910. Verfahren zur systematischen Erforschung des Erdinnern größerer Gebiete mittels elektrischer Wellen.

[6] [Fischer, University Karlsruhe 2003]

[7] DE254517, filed on 13 April 1911. Verfahren zum Nachweis unterirdischer Erzlager und Grundwasserspiegel mittels elektrischer Wellen.

[8] *..Zwei Antennen S und E werden parallel dicht über dem Boden ausgespannt. Die Empfangswirkung in E rührt, falls sich unter dem Erdboden eine reflektierende Fläche befindet, teils von den reflektierten, teils von den direkt durch die Luft übermittelten Wellen her. Durch Veränderung der Wellenlänge der ausgesandten Strahlung kann man - ohne den gegenseitigen Abstand des Senders und Empfängers zu ändern - durch Beobachtung der Interferrenzmaxima und -minima des Vorhandensein und die Tiefe der reflektierenden Fläche feststellen. Sind* $\lambda_1 < \lambda_2$ *zwei aufeinanderfolgende Wellenlängen, für welche etwa ein Minimum beobachtet wurde, so ist der Gangunterschied* Δ. $\Delta = (\lambda_1 \lambda_2)/(\lambda_1 - \lambda_2)$ *und die Tiefe h*
$h = ½ \sqrt{\Delta^2} + 2\alpha\,\Delta$ (α being horizontal distance between S and E)

[9] DE377187, filed 5 February 1920. Verfahren zur Feststellung der Lage elektrisch leitender Flächen in der Erde mit Hilfe der Reflexion elektrischer Wellen. ...*des Verfahrens in bekannter Weise elektrische Wellen Verwendung finden. Das Verfahren beruht auf dem bekannten Prinzip*

as it states that it is a known practice to use reflections of EM waves. However, they should never have been granted this patent, as it clearly infringed earlier patents.[10]

Several years later, on 3rd July 1922, Löwy applied for an Austrian patent by which he claimed: - A system for measuring the distance of an electrically conducting surface (object).[11] He obtained equal patents in other countries as well.[12] (We omit his other patent applications in this field)

Let us look at some of the text of his American patent application, because US patent applications are usually most detailed.[13]

Means for Electric Proof and Measuring of the Distance of Electrically Conductive Bodies

Following his specifications:
My invention relates to means for electric proof and for the measuring of the distance of electric conductive masses, such as subterranean ore deposits and ground water and for ascertaining of the height of flying vehicles, that is the distance of such vehicles from the electric conductive surface of the earth. Such means are based upon a principle which can be called the electric counterpart of the gearing method of Fizeau[14] for measuring of the velocity of the light. The difference resides in that instead of waves of light there are used electric waves and instead of measuring the velocity of transmission, there is measured from the known velocity of the electric waves the unknown distance of the reflecting surface. For the toothed wheel which Fizeau's experiment periodically uncovers and covers the source of light, I substitute according to my invention an arrangement which alternately puts the transmitter and the receiver out of action. Suppose the sender and the receiver are both connected with the same antenna, the antenna is acting as receiver of the wave which are sent out by itself. The arrangement can also be used for simultaneously sending and receiving.
The operation is as follows: During the (extremely short) time during which the sender is in action, there he sent out a wave train which is closely limited with regard to the time and

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der Reflexion elektrischer Wellen und...

10 Such as, for instance: DE273339, filed 26 March 1913, on Gotthelf Leimbach

11 AT3200 application number (not equal to patent number), filed 3 July 1922, Class 42c. According records held at the British Patent Office (BL), it was found that he took his Austrian claims back on 15 August 1925. (Zurückziehungen und Versagungen p. 202 Nr. 12, at BL patent section)

12 BE223957; DE403939; FR574968. Modern EC classification: G01S13/12, G01V3/12

13 US1585591, filed on 17 July 1923.

14 Armand Hippolyte Louis Fizeau, born on 23 September 1819 in Paris, he died on 18 September 1896 in Nanteuil-le-Haudouin France.
He measured in 1849 by means of his famous "toothed wheel" apparatus and a mirror placed at some distance, that the speed of light should be 313.300 km/s. Today, according to NBS (US), we regard: 299792.4574 km/s (± 0.0011 km/s) as the speed of light in vacuum.

which is returning to its starting point after reflection from any reflecting surface which may be anywhere existing.....

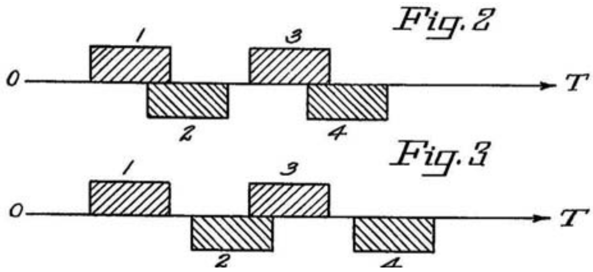

Figure 1

Figures 2 to 3 symbolize the transmitting and reflected time frames. It is clear that the upper pulses represent the transmission bursts and the lower bursts are indicating the time delay owing to its (double) transit time over the route from source → target → receiver. Löwy described the velocity of propagation being C_t /2. We have used this obvious explanation to show how well aware Löwy was how his system should work. Compared with modern technology, the practical application was, of course, very outdated.[15] What counts historically, is the introduction of pulsed signals and the knowledge of measuring the transit-time between transmitter and reception of the returning (reflected) signal. In my opinion what is also significant is, that he mentioned “ascertaining the height of flying vehicles” (aircraft).

About 1926, the Americans Gregory Breit[16] and Merle Antony Tuve[17] found a way to prove the validity of Kennelly’s[18] and Heaviside’s[19] ionospheric layer theory. However, in Britain Appleton[20] and Barnett[21] research on the physics of the ionosphere was a head of Breit and

[15] Nevertheless (although not explained in this paper), implementing an electronic cathode ray switching device creating short time gates, may very well be called advanced in his days. The principles of Löwy’s patent is very good explained in Guerlac’s book p.46 - 48

[16] He was born on 14 July 1899 in Nikolayev in Russia. He died on 11 September 1981 in Oregon(?). He arrived from Russia in the US on 30 July 1915.

[17] Merle Antony Tuve was born on 27 June 1901 in Canton South Dakota, he died on 20 May, place? His grandparents came from Norway.

[18] Arthur Edwin Kennelly was born in Colaba near Bombay India, on 17 December 1861 (son of an Irish naval officer). He died in Boston USA on 18 June 1939.

[19] Oliver Heaviside was born on 18 May 1850 in Camden Town (London). He died on 3 February 1925 in Paignton (Devon) UK.

[20] Edward Victor Appleton was born in Bradford on 6 September 1892. He died on 21 April 1965, place?

[21] No further details could be traced.

Tuve's work. On 11 December 1924[22], Appleton and Barnett did, for the first time, radio propagation investigations on 11 December 1924, for which experimentation Appleton received the 1947 Nobel Prize for physics.

Let us follow some lines of Louis Brown's book[23]:

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 long-wave sets that dominated maritime communications at the time. They noticed interference and standing wave 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 defence discussed.

However, Breit and Tuve used (in contrast) pulsing signals to measure the vertical height of the ionospheric layers considering the shortwave frequency spectra.[24] Their principles were basically similar to what became later known as radar.

It seems that the research into "distance measuring by means of electromagnetic waves" was not progressed for some years to come.

However, Jetson.O. Bently[25] on behalf of General Electric Co in the US applied, on 10 August 1928, for a patent[26] on:

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[22] Two papers appeared: Local Reflection of Wireless Waves from the Upper Atmosphere, Nature 115 (March 1925), p.333-334.
On Some Direct Evidence for Downward Atmospheric Reflection of Electric Rays, Proceedings of Royal Society, A 109 (1925) p.621-641

[23] A Radar History of World War II, p.42-43

[24] However, according to Louis Brown p.43-43: *They had an NRL transmitter modulated with a sine function and measured the phase lag between the modulation of the wave received directly and their laboratory and of the wave reflected off the ionosphere. The transmitter was soon changed to pulsed modulation, which greatly improved accuracy...*

[25] I could not trace information on him. Only that he studied about 1920 at the Union College in Schenectady N.Y. Which town could implicate, that he was engaged by General Electric.

[26] US2011392, granted 13 August 1935. The about seven-year difference might be due to legal challenges. It was also granted in Germany DE509717 (on the name of AEG), in Belgium BE362909 and in France FR679881.
EC classification G01s1/02. AEG filed a simplification DE538843, date 12 July 1930 (additionally to DE509717).

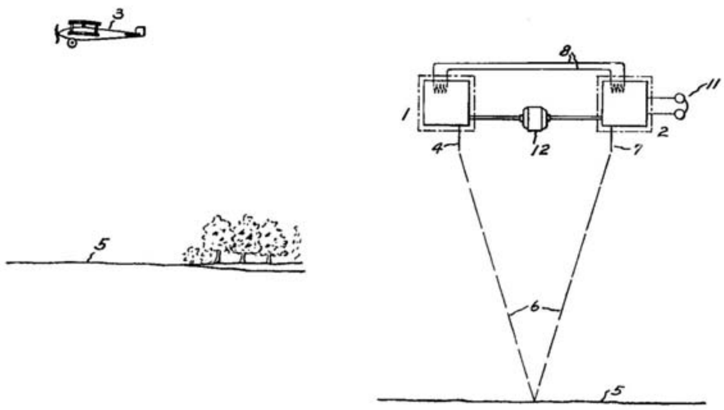

Fig. 3.

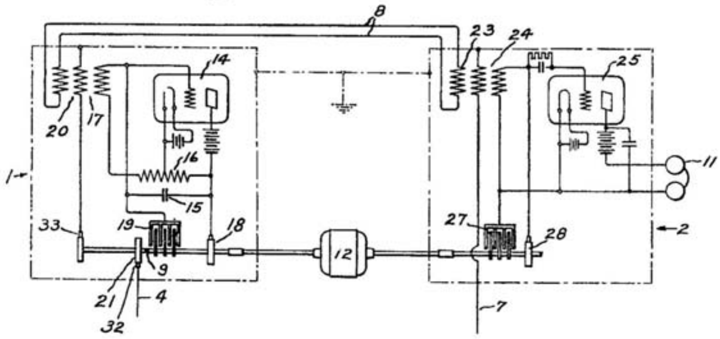

Figure 2

Airplane Altitude Indicating System

He specified:

My invention relates to altitude indicating systems for airplanes and it has for its purpose to provide a novel method and improved means employing radiated electrical waves whereby an indication of the height of the plane above the earth may be had.

In carrying my invention into effect I arrange upon the airplane means for radiating a high frequency wave of preferably linearly varying frequency. As is already well-known, due to the conducting properties of the earth, a portion of this radiated wave which reaches the earth will be reflected towards the plane. I then provide upon the plane means of receiving the reflected wave and also for receiving a wave from the transmitting, or radiating, means directly. The two received waves, one of which is received directly from the transmitting means and the other of which is received from the transmitting means after having been reflected from the earth will be of different frequency due to the difference in the length of the path over which the two waves travel. This difference is frequency will correspond to the change in frequency of the radiated wave which takes place during the interval required for the wave to traverse the path to the earth and back. According this difference in frequency will constitute an index of the altitude of the plane above the earth. I therefore, provide upon the plane means for producing a current having a frequency determined by the difference in frequency between the two received waves and utilize this current to operate suitable *indicating apparatus whereby the operator may be continuously informed as to the altitude of his plane above earth.*

Nowadays it can be explained in simpler terms: - the beat frequency between the direct waves from the transmitter and that of those being reflected from earth, can be read off an electrical altitude or height-indicator (*suitable indicating apparatus*) in the cockpit. This type of technology is called FM radar.

Position number 1 (figure 3) represents the transmitter unit and position number 2 contains the beat-detector(receiver). Number 11 represents the "suitable indicating apparatus" which is symbolized by a headphone. The latter device never could have been used in reality as human ears could hardly cope adequately with such kinds of beat signals.

Bentley fed the direct reference signal from the transmitter towards the receiver by means of a wire coupling. Whereas the later systems, such as the German FuG 101(a) during WW II, used wireless (feed back)coupling between the antennae mounted into both wings of the aircraft, which are shown in figure 2, successively with the positions numbers 4 and 7.

One might get the impression that FM radar-like technologies were virtually forgotten after Bentley filed his "altitude measuring apparatus". However, this can hardly can be true as, in Wireless World of 1939, articles appeared about a "Radio echometer" for aircraft.[27] [28]

What happened in the early 1930s in Germany?

In Germany the naval torpedo research establishment, abbreviated TVA (**T**orpedo**v**ersuchs**a**nstalt) later known as NVA (= **N**achrichten-**V**ersuchs**a**nstalt) in Kiel was highly committed to sound location technologies. One of their outstanding researchers was the physicist Rudolf Kühnhold[29] who was engaged, initially, as a civilian employee.

About 1931 or 1932, Kühnhold came up with a clever idea. He considered that what works in the field of sonar (acoustics) must also work with electromagnetic waves too. It should not be overlooked that when we compare the formulae used for computing radiation fields of

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[27] Wireless World 2nd February 1939 p.100-102, Wireless Altimeter "Echo Sounding" for aircraft. Subject Western Electric Model I altimeter. A quite informative article explaining the nature of FM radar technology.

[28] Wireless World 31 August 1939 p. 226 (the last edition before WW II) Subject recent inventions. USW (= Ultra Short Wave) Radio Altimeter, Standard Telephone and Cables Ltd. (assignees of R.A. Heising) Convention date (granted) USA 15 May 1937, GB5094767, (US2183399) also FR837999; EC classification G01S13/32, G01S13/46. Inventor Raymond A. Heising on behalf of Bell Telephone Lab.

[29] He was born on 27 August 1903 in Schwallungen near Meiningen (Thüringen), he died in 1992, date and place?

acoustic waves with those used for electromagnetic waves, there exists a remarkable similarity. His conclusions proved to be valid!

Let quote from my contribution at the annual CHiDE Symposium at Bournemouth University in 2002.

...Most of us are indeed familiar with the circumstance that organisations are, generally, heavily dependent on their annual budgets - particularly like military services. It can often take years before a non regular budget receives approval: the German Navy (Reichsmarine) was no exception here. To by-pass long and exhausting discussions with superiors, they searched for a rather flexible (and small) company that could solve electrical and electronic demands without being bogged down in bureaucracy. They came in contact with two young engineers. Paul Erbslöh[30] and Hans-Karl von Willisen[31], who, since about 1931, had owned the Tonographie company in Berlin and who were successfully involved in the fields of sound and gramophone recording.

To continue this retrospection: about 1933 Kühnhold discussed with the two partners, Erbslöh and von Willisen, his failed experiments on 13.5 cm wavelength (using 0.1 watt radiated power) with which he tried to detect the bouncing phenomena of high frequency signals on metal objects. In the meantime, Kühnhold continued his experiments with improved Pintsch apparatus on 13.5 cm which used increased transmission power of 0.3 watt (according Harry von Kroge they used Barkhausen-Kurz valve(s) designed by Hans Hollmann, which are also known as retarding field valves). It is a contradiction that most references mention the use of a magnetron! The antenna dipole was, for this experiments, mounted in a parabola dish. On 12 May 1934 Kühnhold was able to measure distance of the try vessel "Grille" at a distance of 2100 m. It is clear that Erbslöh and von Willesen knew soon about Kühnhold's efforts. And it is understandable that there was competition as to who would be come up with a reliable radar-like installation first!

Erbslöh's and Willisen's own attempts had still failed to measure the distance of metal targets, owing to overloading (blocking) of the radar receiver. However, their trials, in cooperation at the NVA testing-site, during 12 October and 2 November 1934, ultimately brought the so desperately needed results. They were now able to measure distance of vessels for up to 12 km. The German Navy instantly ordered the continuation of this research project for which they soon found the necessary funds!

For the course of history is it interesting to know that their patent application was soon rejected because the clerk of the patent office showed these somewhat bewildered men Christian Hülsmeyer's German patent applications of 1904!

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[30] Paul-Günther Erbslöh was born on 18 June 1905, died on 18 February 2002 in Berchtesgarden.

[31] Hans-Karl Freiherr von Willisen was born on 19 April 1906 in Berlin Charlottenburg, he died in 1966 in Wuppertal, place date?

It was also the first time that a patent officer took notice of what had already been so obvious![32] It is, in my opinion, evident that Kühnhold had not done enough abstracting of patents and scientific references as additional sources of information.

The Hülsmeyer patent history has been discussed in this publication extensively so, I don't think any further comment is necessary.

*To close this sub-paragraph, the NVA (ie, the Navy), together with Erbslöh and von Willisen established a new corporate enterprise (which was in those days a very unusual practice) and which was named **G**esellschaft für **e**lektroakustische und **m**echanische **A**pparate m.b.H, abbreviated GEMA. (The present German company Gema has no links, whatsoever, with the previous company, as this is Germany's copyright organisation!)*

I will not go into the details of the development of the Gema company, as this has been dealt with by so many historians.[33]

What happened in the US?

In the late 1980s I came across a pre-war article in a German technical magazine[34] called: Neuere Versuche zur Erzeugung extrem kurzer Wellenlängen mit Magnetfeldröhren (6 mm bis 5 cm), by Hans Awender. i.e. New experiments generating extreme short wavelengths, between 6 mm and 5 cm, by means of magnetrons.

Based upon an article in an American periodical[35] it dealt, among other things, with power magnetron experiments on 4.8 cm, by Chester W. Rice.[36]

Awender explained Rice's power magnetron technology which provided 3 watts (maximum power 10 watts CW) at 4.8 cm (6.25 GHz), into an antenna. It required water cooling of six litres per minute. Of special note was that the magnetic flux and the anode voltage could be modulated by means of special provisions. Of note was also that the magnetron and the coaxial feed (transmission line), inclusive of its ¼ λ antenna rod (1.1 cm long), was an

[32] This story was personally told by Erbslöh during an extensive telephone conversation in Spring 1997.

[33] Russel Burns, Harry von Kroge, Louis Brown, and others.

[34] Funk technische Monatshefte (FTM) Heft 11 / 1937 p.347-349

[35] Transmission and reception of centimeter radio waves. Ch.W. Rice. General Electric Review 39, 363, 1936.

[36] Chester W. Rice was a Fellow of the Institute of Electrical Engineers (since 1928). And a Fellow of the American Institute of Electrical Engineers (named in 1939). Further data unknown.

integral part of the described magnetron unit. They used 60 cm parabolic reflector units[37] for an experimental radio link (4.2 - 4.8 cm) covering 12 km distance. Also, a new type of front-end valve had been discussed. It was based on the Barkhausen-Kurz principle (also known as retarding field technology).[38] So far, the description might sound rather fascinating for the 1930s, but not regarding when compared with today's, state of the art, technology. My attention became drawn to this subject after Rice described that they also measured the velocity of cars, at a distance of about 2.2 km, by means of the Doppler phenomenon.

If we consider that it was said that radar developments progressed slowly in the 1930s, then we may be surprised that the Doppler shift was measured over a reasonable distance at a wavelength of 4.8 cm. This is, in my opinion, pure radar technology practised about the turn of 1935/1936!

I bore this article in mind, for a future reference. When I became engaged in the project concerning Christian Hülsmeyer and the early days of radar, I thought that this should be the opportunity to find out more about Rice's work in this intriguing field.

Some years ago, I had already found a patent application filed on behalf of AEG, with the inventor named as of Chester W. Rice, Schenectady, New York.[39] This was also the home town of the Research Laboratory of General Electric.
It claimed, a (radar like) apparatus to measure the relative radial velocity of metal objects.

Thanks to Tom Going, a source was revealed of a totally unexpected nature!

To keep the story within the framework of this publication, I have selected the main patents which, ultimately, covered nearly all of what was necessary to claim a mature radar-like apparatus (system).

[37] They used housings and the mirrors of airport beacons (lights) [General Electric Review Vol 39, August 1936, p.365]

[38] See, GB491445, US 2156016, US2156017. The US versions gave as inventor G.A. Hobart, however it was owned by General Electric USA. Curious is, that he claimed equal valve constructions as in Rice main patent, but with a gaseous (mercury) vapour content!

[39] DE754838 filed on 11 October 1936, which was granted on 14 September 1944. It mentioned that it considered the US priority of 9 April 1936. *Anordnung zur Bestimmung des Bewegungssinnes eines hochfrequente elektrische Wellen reflektierenden Körpers relativ zum Meßort.*
As we know, AEG had strong links with several US companies.

Let us examine some of the text of the British patent GB497147[40], which was filed about half a year after AEG had filed a similar invention. The German patent version claimed fewer applications but, might have been due to the time it took to get things formulated correctly.[41]

The original US claims were all on behalf of General Electric, the mightiest electrical conglomerate of the US. To prevent confusion, it was not associated with British GEC. However, it owned the British Thomson-Houston Company Limited, who was also the applicant for the patents in Britain, France and Belgium.

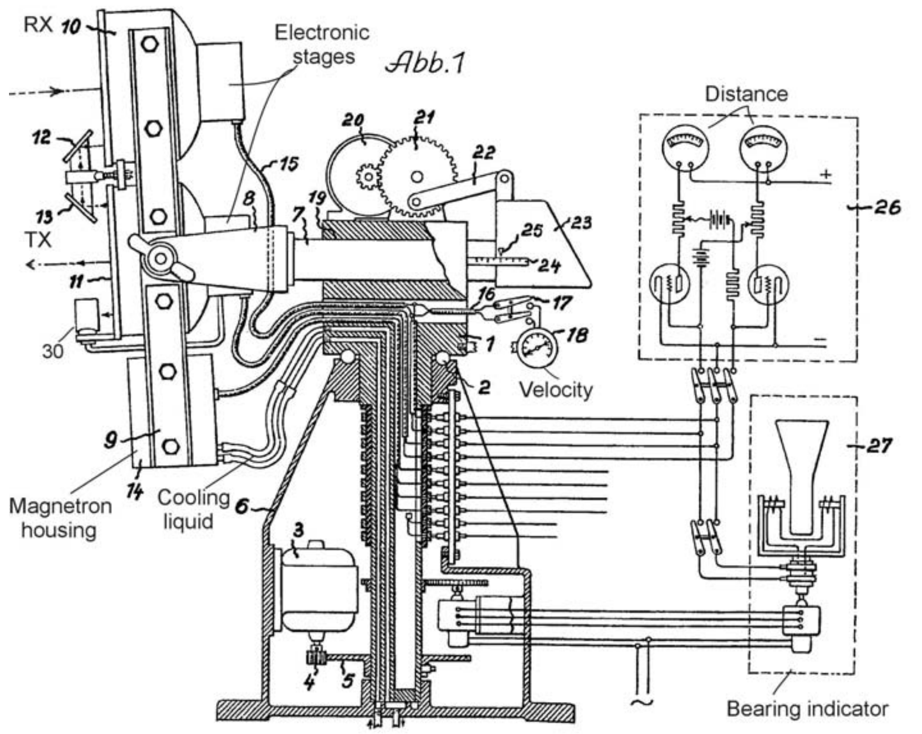

Figure 5

However, GB497147 claimed:

Improvements in and relating to Radio Direction and Range Finding Apparatus

Let us follow some lines of the patent specifications:

[40] filed on 9 April 1937 and granted 9 December 1938! (according a stamp printed at the header "uitgegeven 12 Jan. 1939", this is curious, because this is Dutch language)

[41] It was linked to: US2412631; GB497147; FR820350; BE421006.
EC Classification G01S13/32, G01S1/02. It is also plausible that additional claims had to be arranged.

...This invention relates to apparatus for indicating the bearing and range of a distant object from a given location utilising the transmission of a beam of ultra short waves transmitted from the location and received after reflection from the object.
It is well known that radio waves length of 10 centimeters or less behave more or less as optical waves, being subject to the laws of reflection, and being capable of being formed into a narrow beam in a manner similar to light waves.

So far, the patent claims are quite clear, although, in 1936, not so many would have been prepared to consider employment of high power sources in the centimetre wave ranges!

However, I have selected the figure 5 from the German patent application[42] which, due to its simplicity is easier to understand. This drawing is, of course, much simplified and electrical components only represent the basic principles. When valves are shown, this only indicates that an electronic circuitry is involved, and does not necessarily mean that it only consists of one stage!

It is interesting to note that the shapes of the units represented by the position numbers 10 and 11, have remarkable similarities with the device shown in the General Electric Review paper of 1936. Even with respect to their laboratory set up!

An intriguing feature is the bearing display part number 27 of the previous figure. It has much in common with what became later known as PPI. The deflection unit is servo linked to the movement of the antenna arrangement. It was capable of 360° rotation which made it available for a total scan or selective sector searches.

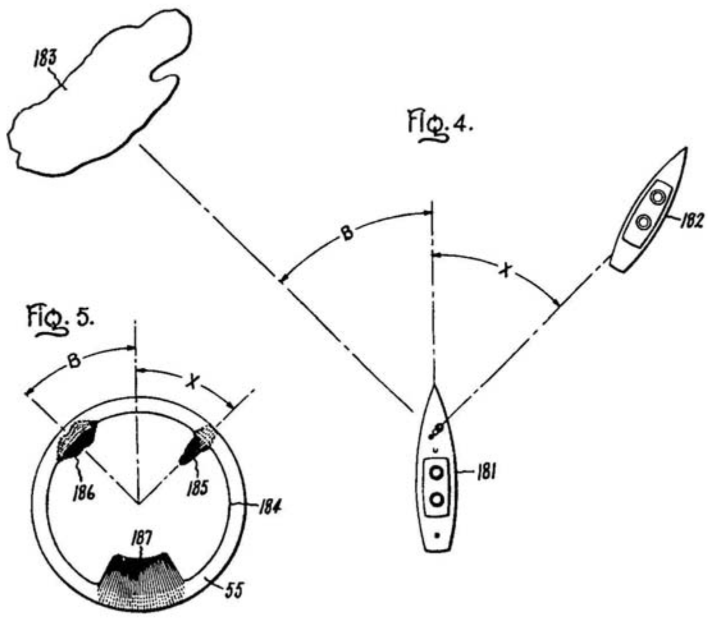

Figure 4
Shown here is the round search mode of an installation. The video output signal of the radar receiver modulated the deflection coil which, of course, will impinge on the circular trace

[42] DE754838

(spot) painted on the CRT screen causing a radial deflection of the CRT trace. The radial modulation was directly linked to the incident bearing. Rice considered that cm waves act, more or less, like optics and that the shape of the reflecting body may be recognized on the CRT screen. Number 182 shows a ship and 183 an island. Number 187 shows the ship structure, looking aft.

The more advanced patent claims of the spring of 1937 considered two types of system operations. One being the regular distance measuring, by means of pulsed transmitted signals (he considered one microsecond pulses being adequate). To measure the distance at a certain bearing the antenna rotation had to be stopped at that point and the distance could be read off a moving-coil indicator.

The second mode was measuring speed by means of Doppler phenomena. For this occasion the magnetron transmitter was switched to continuous mode (CW). The antenna installation had to be pointed at a certain target and the velocity could be read off a calibrated meter-scale (position 18).

We have already seen that, from the top of the roof of GE's research lab, they measured the velocity of cars at about 2,2 km distance. As we know, this Doppler effect is caused by the radial velocity of a reflecting object. To measure the relative frequency change at very high frequencies, one needs a stable reference. This was very elegantly solved by Rice's group. They took a controlled amount of the radiated energy by means of the two reflecting plates 12 and 13. Between it they placed a so-called iris-diaphragm, so as to control the signal level fed onto the receiver at the focus of the parabolic system. When a signal returned from a moving-target (object), the direct and returned signals interfered, and created a beating signal, which could be rather simply monitored and measured.[43]

Provisions were also made to prevent mutual interference, when two or more similar systems were operating in the vicinity of each other. They used, even during their lab. experiments, polarized shields or grids. These were most effective when placed at an angle of (+/-) 45 degrees to the vertical plane. They discovered that reception could be improved when two polarisation grids were being employed in cascade.

In addition they also noted the presence of particular radio echos. Let us follow Riche's paper[44]:
In the case of moving objects, there is, besides the modulation due to the Doppler-effect, what might be called chopper modulation - that is, a variation of scattered and reflected radiation. We observed this effect very clearly when listening to the small 6-bladed paddle wheel or Soroco type of fan which was mounted on the top of a nearby building. The fan was run at 1750 rpm... The chopper frequency of f = 1750 x 6/60 = 175 cycles was about equal loudness to the Doppler frequency caused by the linear blade velocity of........ 632 cycles.

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[43] Rice also considered, that one could employ adjustable polarization grids, so as to control the level fed into the receiver parabola. The transmitting power was also controlled by means of a detecting device (position 30) mounted near the edge of the radiation field.

[44] [p.369]

It is interesting to note that, Taylor, Young and Hyland had already patented:-[45] [46]

System for Detecting Objects by Radio

Some lines:
This invention relates to a method of and means by which moving objects in the air or on the surface of the earth may be detected by the employment of radio receiving and transmitting equipment..... In the previously issued patents directed along similar lines, reflection has been the basic phenomenon. These patents, in every case, have to do with location of objects or determination of altitude by means of reflected waves.....
at page 2 line 65
In (fig 3) is shown the ordinary phenomenon plus that due to propeller effect, S^2. The interference due to reradiation from the airplane is considered to be the interference of a wave of fixed polarization and the ground wave which is also fixed polarization. The interference due to the propeller effect is in a different category, since the changing position of the propeller constantly changes the polarization of the reradiated wave.....

We can learn, from this additional material, that most phenomena were already known, at least, to some people in the scientific community!

Let us close this chapter by noticing what Rice thought about future applications of their inventions.[47]

Applications
In conclusion it may be of interest to list some of the applications which become possible with the advent of radio optics.
(1) Point-to-point beam communication
(2) Wide side-band communication over a chain of automatically repeating beam stations spaced 15 to 20 mi apart. This might be termed a radiation transmission line. This type of line would appear to be practical way of distributing television.
(3) Fog light for navigational purposes.
(4) Airplane landing beams and direction markers.
(5) All-weather airway beacons.
(6) Radio-beam protection of drawbridges, harbor, etc.
(7) Doppler detection of moving objects including relative line-of-sight velocity and distance.
(8) Airplane ground speed indicator.[48]
(9) Radio searchlight using modulation.

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[45] Albert H. Taylor and Leo C. Young and Lawrence A. Hyland. US1981884. Filed 13 June 1933, granted 27 November 1934.

[46] See also [Burns, p.30 - 33]

[47] [p. 369]

[48] For instance, US2193361 filed 9 April 1937; FR820350 filed 8 April 1937 in the main patent. It is curious, that the British main patent of 9 April 1937 lacked this claim.

(10) Radio-echo altimeter.
(11) Radio-echo locator for navigation.

We may finally conclude, that they were very well aware of future implications. In my opinion, this vision must reflect, at least in some respect, the forward thinking of some of the research lab. of the General Electric Company.

Reflections on aspects of the early days of radar

In this brief publication, I have neglected the many stories (and fairy tales) relating to the early days of radar, as these have been dealt with by many authors.[49]

I have to make an exception for Gutton's radar trials on S.S. Normandie in 1935. Although these trials ultimately failed, the French proved that they took notice of available references (and no doubt gave the whole matter a great deal of thought) which lead them to build a CW radar system. Gutton started about 1933, however, his apparatus broke down during its first trip to New York in July 1935. Nonetheless, they continued working in the fields of radar technology at very high frequencies.[50]

However my aim has been to show that the history of early radar developments should not be credited to only a few famous names. Likewise I wanted to point out that it was the general neglect of information that had already been available from open sources, such as patents and scientific papers, that hampered the progressing and development of what became known - as radar technology.

It is very likely that, developments would have advanced rather differently had the available technical sources been fully digested. For instance, in the 1930s many radar-like experiments started with CW trials, whereas it was already known from (Löwy's early 1920s patents) that pulsed technology was more favourable.

In Europe, there was a rather hampering environment of widespread secrecy on radio-echo technologies, particularly in Britain, Germany, The Netherlands and, other countries. However, most relevant papers and patent applications were available, as we have learned, both in the United States and in Europe. It was simply a case of looking for them to have discovered about the availability and the state of the art of radar-like science.

In this respect it is relevant to consider that the United States of America had, in the nineteen twenties and thirties, not restricted publications on radar-like technologies. Nevertheless, the

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[49] For instance, Russell Burns, Louis Brown, Henry E. Guerlac, von Kroge, and many others.

[50] [Burns, p.45 - 52] Süsskind contributed in Burn's book [p.506-512] also on Gutton and mentioned his patent FR788795, filed 20 July 1934, convention date 16 October 1935, it was on behalf of the company TSF. Which is basically a very brief claim (application).

situation changed dramatically when the Second World War started and America had become involved.

In my opinion, two significant devices (technologies) obstructed the early radar developments one was the lack of high frequency power sources for centimetre waves and the second was the lack of power modulator technologies, capable of generating pulses in the > 100 kilowatts range. All other technologies could have been coped with even if, at sometimes there was some lesser degree of performance.

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Abbreviations

BE	= Belgium (patent)
CEO	= Chief executive officer
CRT	= Cathode ray tube
CW	= Continuous wave
DE	= Germany (patent)
EM	= electromagnetic
FR	= France (patent)
HAD	= Hülsmeyer's family archive Düsseldorf
HAL	= Holland-Amerika Lijn
GAR	= Gemeente archief Rotterdam
GB	= Great Britain (patent)
KB	= Koninklijke Bibliotheek (Royal Dutch Library)
OAN	= Our own Foundation archive number
US	= USA (patent)
ZM	= Folder designation + number

Figure sources

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