Bistatic Radar

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A bespoke one-week course for
Electronics & Radar Development Establishment
Defence Research & Development Organisation
Ministry of Defence
Bangalore, India

17 - 21 December 2012

Day 1

1.1 Introduction to bistatic radars
1.2 Stealth and counterstealth techniques
1.3 Bistatic geometry
1.4 Bistatic radar equation and its implications
1.5 Noise & interference in bistatic radars
1.6 Bistatic clutter

Day 2

2.1 Passive radar
2.2 Properties of sources
2.3 Target properties

2.4 Practical session – measurement and plotting of ambiguity functions of sources

Day 3

3.1 Presentation of results

3.2 Electromagnetic noise
3.3 Effective volume of detection
3.4 Direct signal cancellation

Day 4

4.1 Target association
4.2 Multilateration methods
4.3 Detection algorithms

Day 5

5.1 Matlab session on Direct signal cancellation and detection, implementation methods
5.2 Presentation of results
5.3 Examples of systems
5.4 Winding up session

Further reading

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Special Issue of *IEEE AES Magazine* on Passive Radar, Vol.27, No.10, October 2012

Special Issue of *IEEE AES Magazine* on Passive Radar, Vol.27, No.10, October 2012

Second part in November 2012 !

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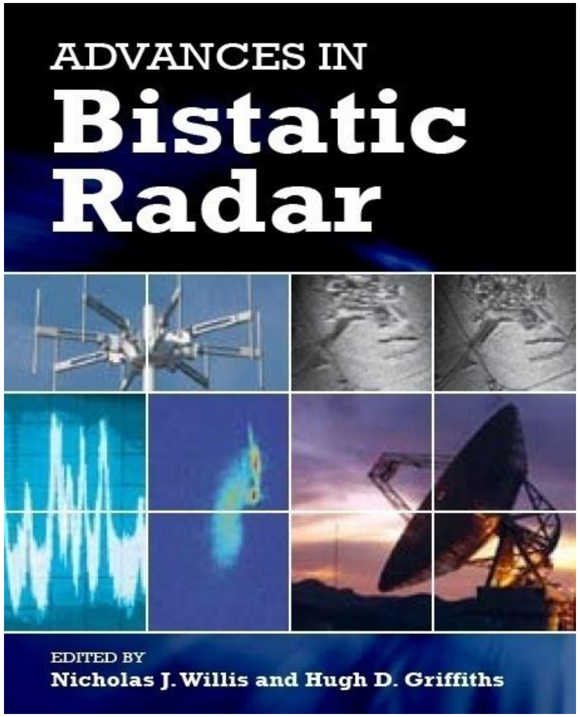


A sequel to Willis, N.J., *Bistatic Radar*, Artech House, 1991

covering advances in the subject since 1991, and including recently-declassified information on bistatic radar systems from previous decades, as well as significant new material on passive bistatic radar.

Bistatic radar: definitions

- **MONOSTATIC RADAR**

  Tx & Rx at same, or *nearly the same*, **location**

- **BISTATIC RADAR**

  Tx & Rx separated by a *considerable* ***distance*** **in order to achieve a technical, operational or cost benefit**

- **RADAR NET**

  Several radars linked together to improve coverage* or accuracy

- **MULTILATERATION RADAR**

  Radar net using range-only data

- **MULTISTATIC RADAR**

  Bistatic radar net with multiple Txs *and/or* **RXs.**

- **HITCHHIKER**

  Bistatic Rx operating with the Tx of a monostatic radar

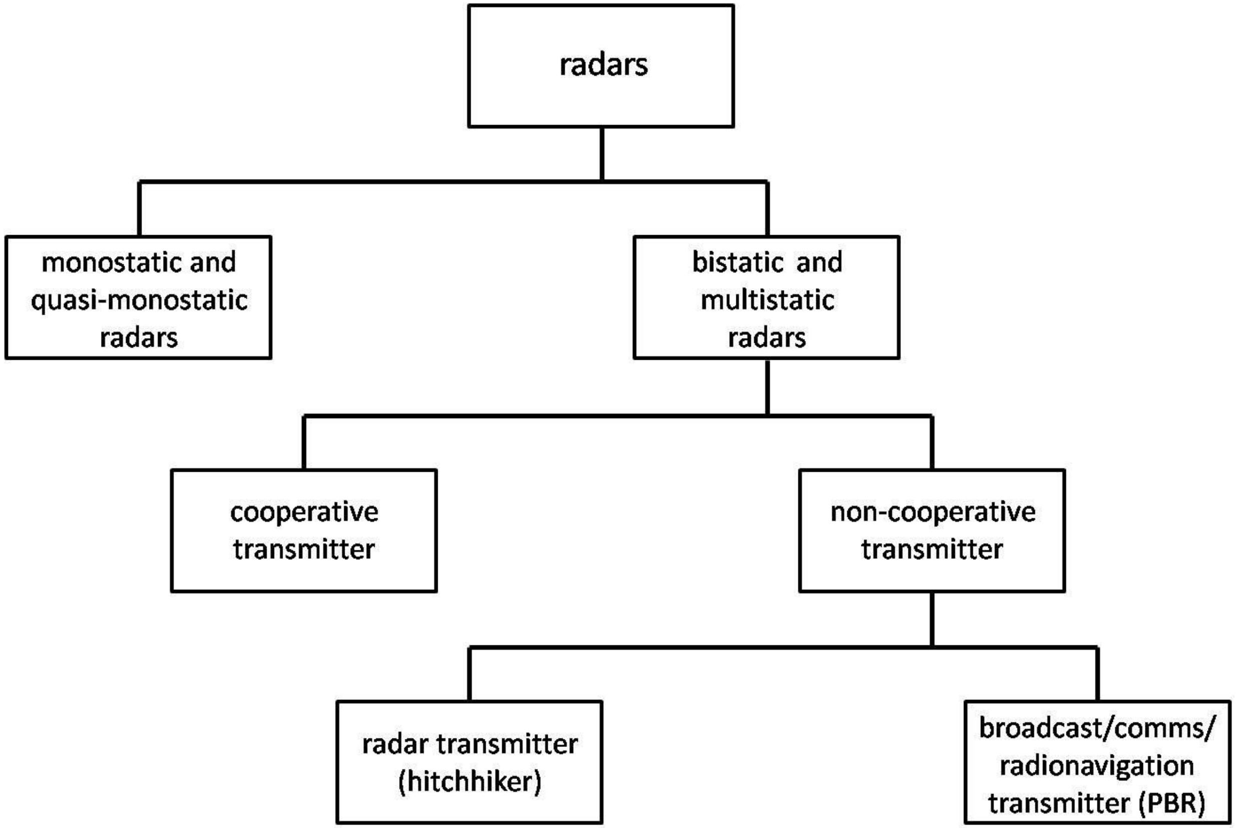
- **PASSIVE BISTATIC RADAR**

  Bistatic Rx operating with other Txs of opportunity

*** Enjoys the union of individual coverage areas. All others require the intersection of individual coverage areas.**

Coverage area: (SNR + BW + LOS)

Bistatic radar: taxonomy



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', *Proc. National Conference of Aeronautical Electronics*, 12–14 May 1958, pp286–290.

Bistatic radar

- Bistatic radar has potential advantages in detection of targets which are shaped to scatter energy in directions away from the monostatic;
- The receiver is covert and therefore safer in many situations;
- Countermeasures are difficult to deploy against bistatic radar;
- Increasing use of systems based on autonomous air vehicles (UAVs) makes bistatic systems attractive, since bistatic operation may remove the need for a relatively small UAV to carry the heavy, complex and power-hungry transmitter;
- Many of the synchronisation and geolocation problems that were previously very difficult are now readily soluble using GPS, and
- The extra degrees of freedom may make it easier to extract information from bistatic clutter for remote sensing applications.

Bistatic radar

- The first radars were bistatic (till T/R switches were invented)
- First resurgence (1950 – 1960): semi-active homing missiles, SPASUR, ….
- Second resurgence (1975 – 1985): SANCTUARY, hitchhikers, multistatic measurement system (Kwajalein), …
- Third resurgence (1995 – present): Passive Coherent Location (PCL): SILENT SENTRY, TV bistatic radar, bistatic SAR, cellphone radar (Roke Manor), …

Willis, N.J., ‘Bistatic radars and their third resurgence: passive coherent location’, IEEE Radar Conference, Long Beach, USA, April 2002.

The first radar – Hülsmeyer, 1904

N° 13,170 **A.D. 1904**

Date of Application, 10th June, 1904—Accepted, 22nd Sept., 1904

COMPLETE SPECIFICATION.

"Hertzian-wave Projecting and Receiving Apparatus Adapted to Indicate or Give Warning of the Presence of a Metallic Body, such as a Ship or a Train, in the Line of Projection of such Waves".—

I, CHRISTIAN HÜLSMEYER of 3 Grabenstrasse, Düsseldorf, Germany, Engineer do hereby declare the nature of this invention and in what manner the same is to be performed to be particularly described and ascertained in and by the following statement:—

This invention consists, broadly, of improved apparatus for projecting electric waves in any desired direction combined with improved apparatus for receiving said waves when reflected back from any metallic body, such as a ship or a train, said receiving apparatus being adapted to put into action an audible or a visible signal and thus give warning of the presence of such metallic body in the line of projection of the waves.

My invention is based upon the property of electric waves of being reflected back towards their source on meeting a metallic body, and will be readily understood by imagining a transmitting and a receiving station such as indicated placed side by side at the same point and so arranged that waves projected from the transmitter can only actuate the receiver by being reflected from some metallic body, which, at sea, would presumably be another ship.

I have illustrated my invention in the accompanying drawing, in which:

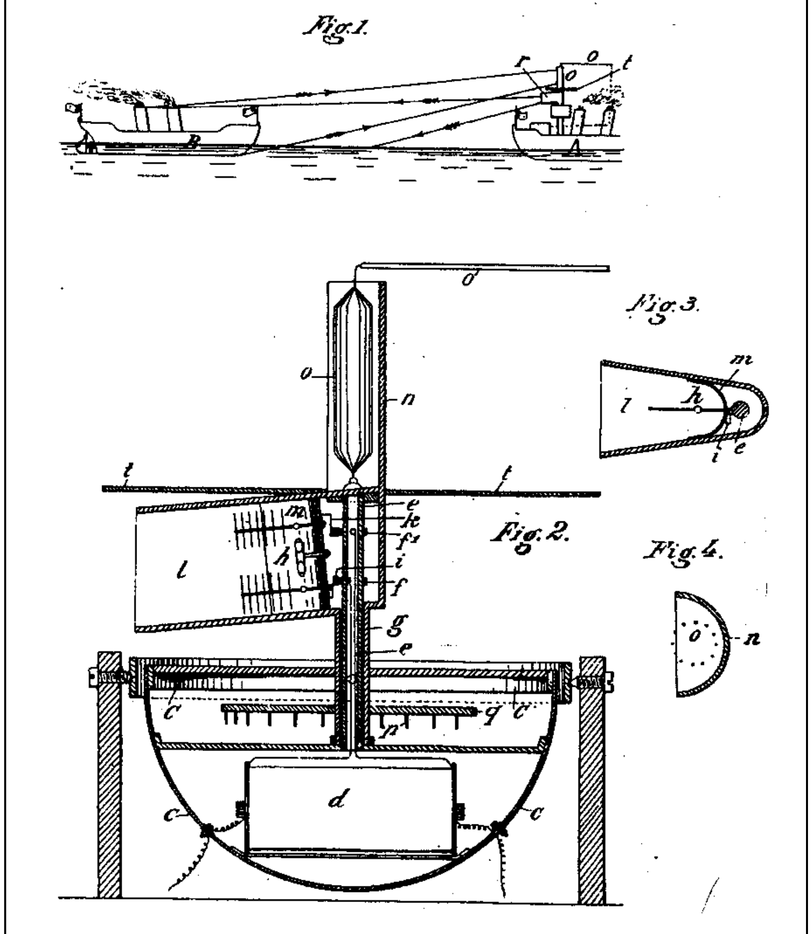
Fig. 1 is a diagrammatic view showing a ship A fitted with my apparatus, and a ship B whose presence is detected thereby.

Fig. 2 is a sectional view of the apparatus, and

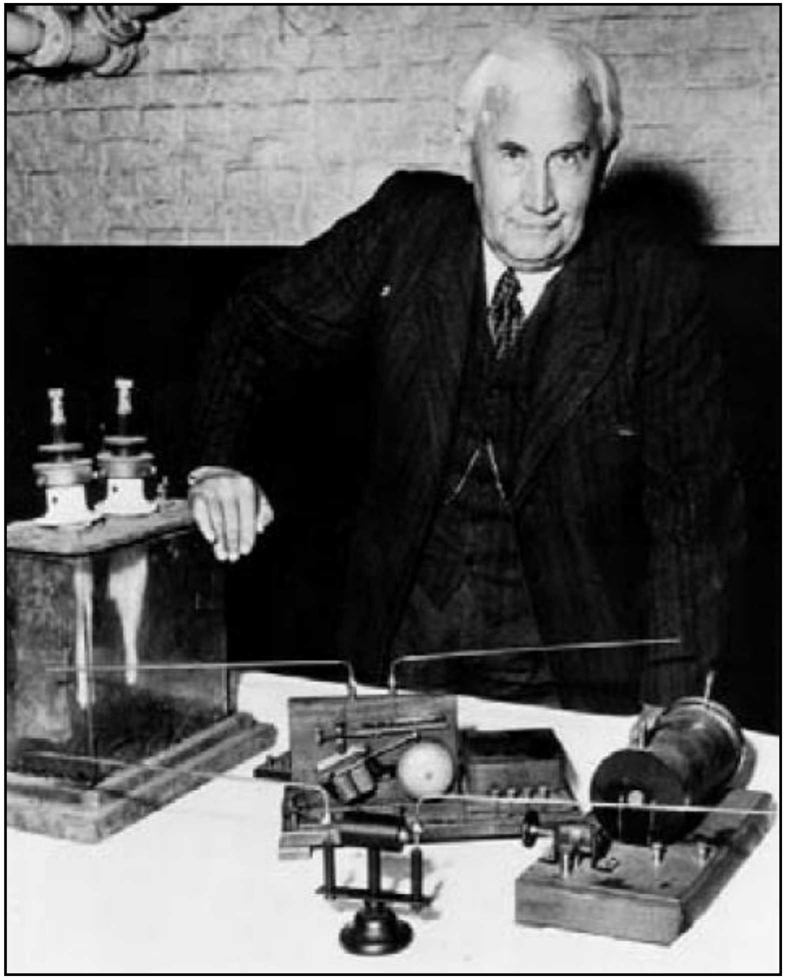
Figs. 3 and 4 are sectional views of details thereof.

My apparatus comprises a transmitting and a receiving station similar to those used in wireless telegraphy, with this difference that the two stations are situated in close proximity to each other and are so arranged and constructed that they cannot directly influence one another. In view of the fact that ships are at times subject to considerable rolling, pitching and like motion, which might otherwise render the apparatus practically useless, I mount both the transmitter and receiver similarly to a compass-box, about as shown in Fig. 2, so that they are maintained by the action of gravity in an approximately vertical position. In the pivotally mounted hollow semi-sphere *c*, I also mount an induction coil *d*, the current from which actuates the transmitter. Said induction coil receives its primary current from any suitable source, for example, from accumulators, batteries, or from a dynamo generating either an alternating or a continuous current. In the case of a continuous current, I provide a suitable transformer. The secondary current of the induction coil *d* is conducted by wires through a hollow spindle *e* to two insulated rings f, f^1, fixed thereon. On said spindle *e*, I rotatably mount a sleeve or the like *g* wich carries or is integrally formed with a funnel-shaped reflector or screen *l* adapted to confine the electric waves emanating from the oscillator *h* and to assist in projecting them in any desired direction. The high tension and correspondingly insulated current from the induction coil is taken off the rings f, f^1 by means of brushes *i* and *k* and transmitted to the oscillator, immediately behind which and within the projector screen *l* a concave reflector *m* is mounted whereby

[*Price* **8d.**]



The first radar – Hülsmeyer, 1904



More history ...

In the autumn of 1922, A.H. Taylor and L.C. Young of the Naval Research Laboratory in the USA demonstrated detection of a wooden ship using a CW wave-interference radar, at a wavelength of 5 m.

In December 1924, Appleton and Barnett in the UK used an FM radar technique to measure the height of the ionosphere, and the following year Breit and Tuve in the USA used a pulsed radar for the same purpose.

The first detection of aircraft using the wave-interference effect was made in 1930 by L.A. Hyland of the Naval Research Laboratory in the USA.

The Tizard Committee

In 1932 in an address to Parliament, Prime Minister Stanley Baldwin stated that there was no hope of defence against bombers: ‘The bomber will always get through.’ This prediction seemed to be borne out by RAF air exercises in July 1934, when at least half the day bomber attacks managed to reach their targets without being attacked by fighters.

Not everyone in the British Air Ministry agreed. In June 1934, a junior Air Ministry official named A.P. Rowe went through whatever he could find on plans for the air defence of Britain, and was disturbed to learn that although work was going into development of improved aircraft, little other work was being done to consider a broad defensive strategy. Rowe wrote a memo to his boss, Henry Wimperis, explaining that the lack of adequate planning was likely to prove catastrophic.

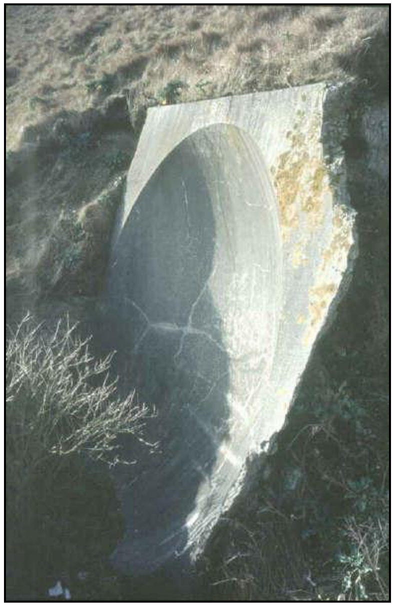
Wimperis proposed that the Air Ministry form a committee – whose terms of reference were to investigate new technologies for defence against air attacks. Wimperis suggested that the committee be led by Sir Henry Tizard. The ‘Committee for the Scientific Survey of Air Defence (CSSAD)’ was duly formed under Tizard's direction.

Greg Goebel, *The Wizard War: WW2 and the Origins of Radar*, http://www.vectorsite.net/ttwiz.html

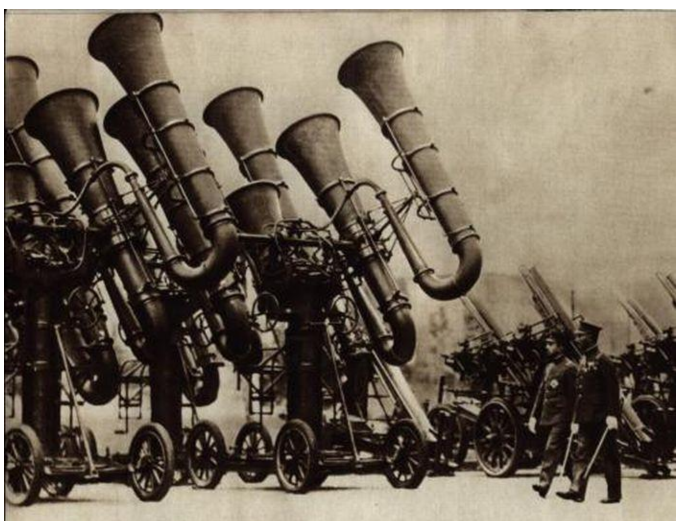
Acoustic detection of aircraft

Before the advent of radar, the only practicable means of detection of aircraft was acoustic, and a network of acoustic detectors was built in the 1920s and 1930s around the south and east coast of the UK, some of which still remain.

In calm air conditions, detection ranges of up to 25 km were achievable.



Acoustic detection of aircraft



More history ...

In January 1935, Watson Watt had been asked by Wimperis to investigate the feasibility of electromagnetic ‘death rays’ to disable aircraft. Arnold Wilkins and he concluded, in an elegantly-reasoned piece, that it would not be feasible, but that detection of aircraft using radio waves should be possible. The same year he demonstrated detection of aircraft at a range of up to 8 miles in what has become known as ‘the Daventry experiment’, and by June 1935 he had demonstrated the pulsed radar technique to measure aircraft range.

Death Rays

(12 February 1935)

‘Suppose it is desired to produce physiological disablement in a man remaining for so long as ten minutes in the field of the beam, at a distance of 600 metres. He may be treated as composed simply of 75 kg of water. It is necessary to deliver, over his projected area of 1 sq metre (2 metres high $\times$ 1/2 metre wide) enough energy to raise his temperature by at least 2°C. Making the very unduly favourable assumptions of black body absorption, of 100% efficiency of conversion, without increased cooling by radiation and convection, the reasonable assumption of negligible absorption en route, and the unfavourable assumption of no aid from resonance in draining an area of front greater than the nett projected area, it is necessary to deliver 1.5×10^4 cal/gm per minute. …..

…. It must be repeated that these figures depend on the target remaining within the field of a beam, not worse than 5° in semi-angle of divergence, i.e. within a transverse range of 100 metres at 600 metres distance, for ten minutes. The more practical assumption of one minute sends the required power up tenfold and seems to remove the whole scheme outside practicable limits.’

Detection and location of aircraft by radio methods

(27 February 1935)

‘Let it be assumed that the typical night-bomber is a metal-winged craft, well-bonded throughout, with a span of the order of 25 metres. The wing structure is, to a first approximation, a linear oscillator with a fundamental resonant wavelength of 50 metres and a low ohmic resistance. Suppose a ground emitting station be set up with a simple horizontal half-wave linear oscillator perpendicular to the line of approach of the craft and 18 metres above ground. Then a craft flying at a height of 6 km and at 6 km horizontal distance would be acted on by a resultant field of about 14 millivolts per metre, which would produce in the wing an oscillatory current of about 1½ milliamperes per ampere in sending aerial. The re-radiated or ‘reflected’ field returned to the vicinity of the sending aerial would be about 20 microvolts per metre per ampere in sending aerial. …..

…. If now the sender emits its energy in very brief pulses, equally spaced in time, as in the present technique of echo-sounding of the ionosphere, the distance between craft and sender may be measured directly by observation on a cathode ray oscillograph directly calibrated with a linear distance scale, the whole technique already being worked out for ionospheric work at Radio Research Station. …’

The Daventry Experiment: 26 February 1935

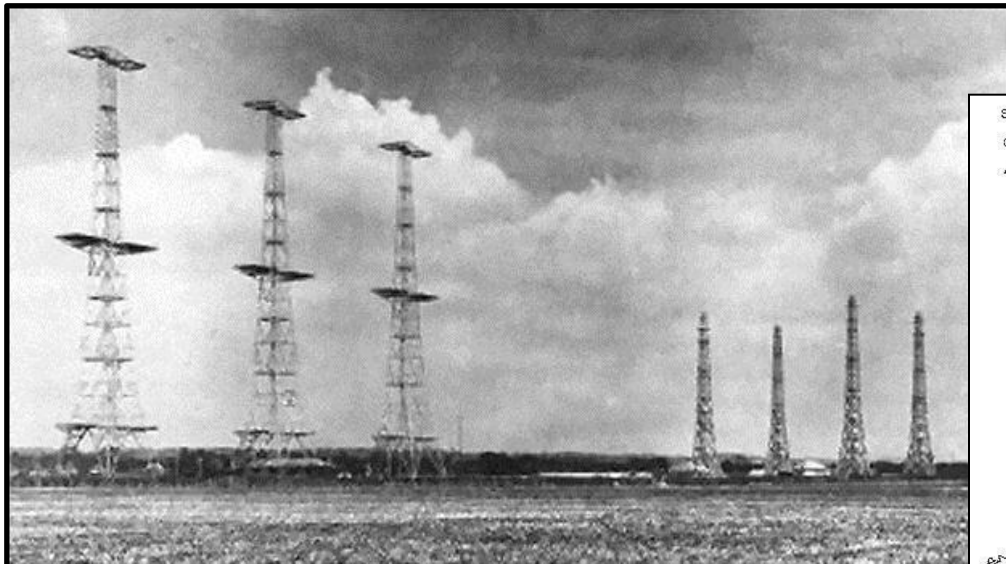
Painting by Roy Huxley

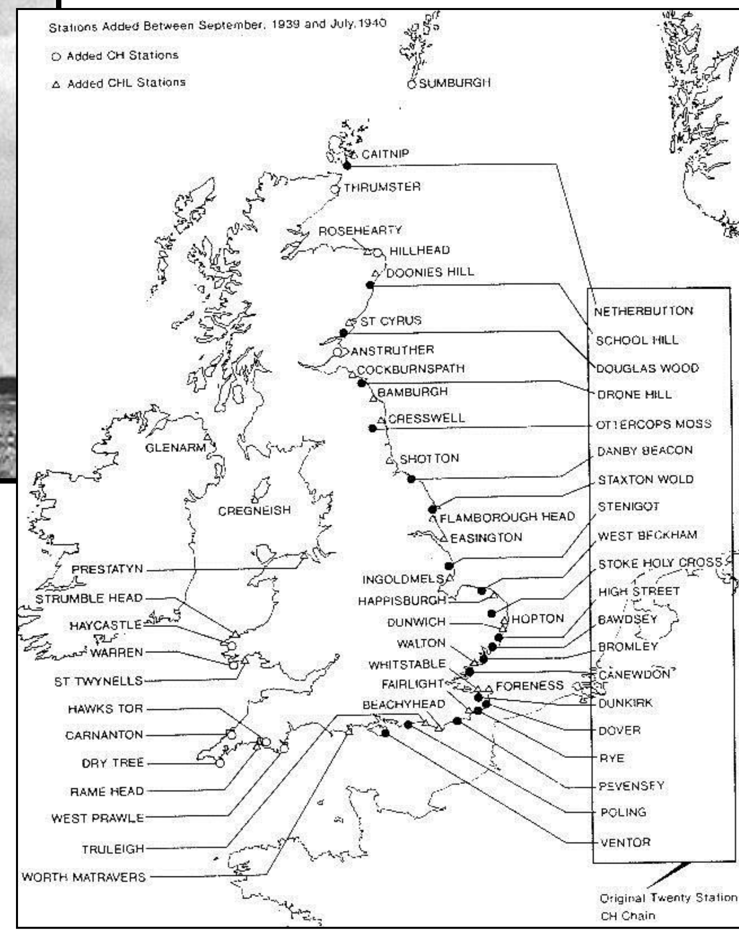
Sir Robert Watson-Watt

Rough Justice

Pity Sir Robert Watson-Watt,
strange target of this radar plot
And thus, with others I can mention,
victim of his own invention.
His magical all-seeing eye
enabled cloud-bound planes to fly
but now by some ironic twist
it spots the speeding motorist
and bites, no doubt with legal wit,
the hand that once created it.
And so, all you courageous boffins
who may be nailing up your coffins,
(particularly those whose mission
is in the realm of nuclear fission)
pause and mull fate's counter plot
and learn with us what's Watson-Watt.

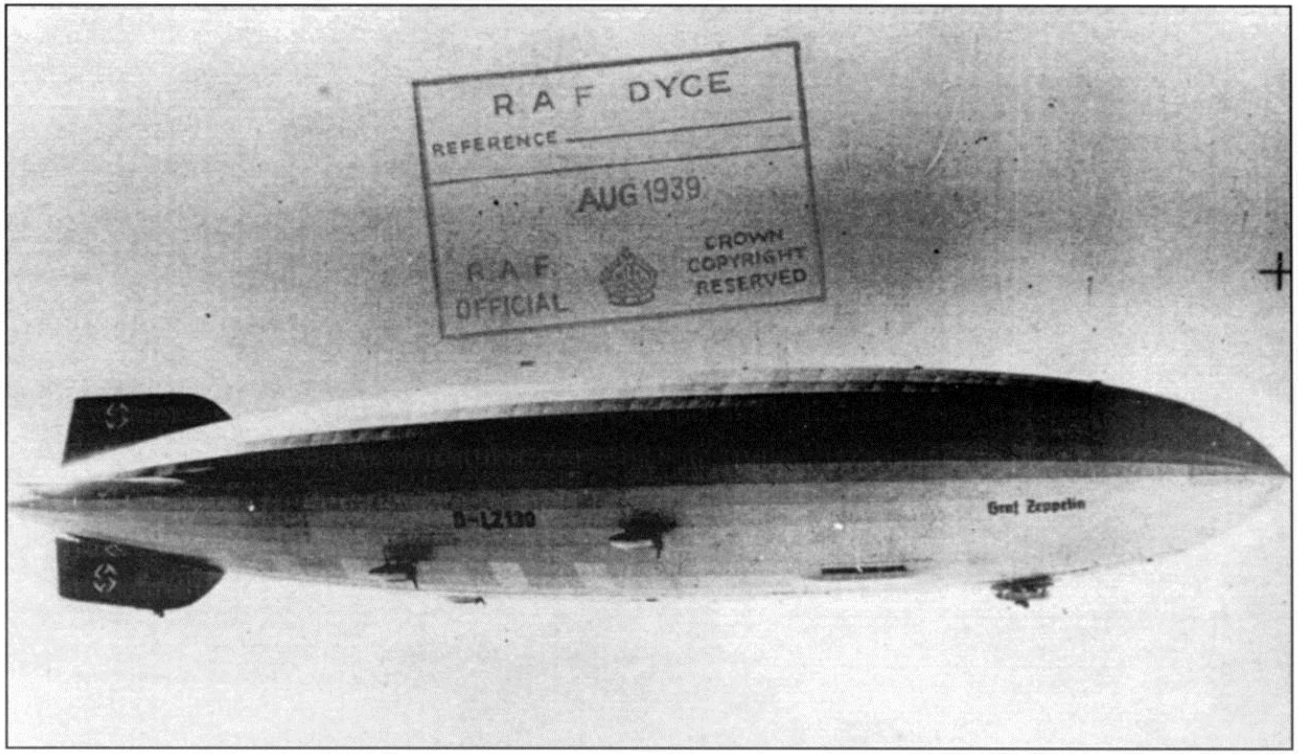
CHAIN HOME





Neale, B.T., ‘CH – the First Operational Radar’, *GEC Journal of Research*, Vol. 3 No.2 pp73-83, 1985.

CHAIN HOME



A Graf Zeppelin airship (LZ-130) with signal interception equipment made an electronic intelligence-gathering mission up the North Sea on 2/3 August 1939, one month before the start of WW2 and (of course) saw the Chain Home stations and detected the Chain Home signals. But they concluded that the low frequency and the low PRF (25 Hz) must be associated with defective insulators on the National Grid, or to radionavigation or communications rather than radar - an expensive mistake.

CHAIN HOME

Peter Flint, *Dowding and Headquarters Fighter Command*; Shrewsbury, Airlife, 1994; Crown copyright

CHAIN HOME

The three Bawdsey secretaries whose success as ‘guinea pig’ radar operators led to the recruitment of WAAF for this role. They are, from the left, Miss H. Booker, Miss N. Boyce and Miss M. Girdlestone. (Imperial War Museum, E(MOS) 1426, 1427).

P.E. Judkins, *Making Vision into Power: Britain's Acquisition of the World's First Radar-based Integrated Air Defence System 1935 – 1941*,

CHAIN HOME

‘The Germans would not have been surprised to hear our radar pulses, for they had developed a technically efficient radar system which was in some respects ahead of our own. What would have surprised them, however, was the extent to which we had turned our discoveries to practical effect, and woven all into our general air defence system. In this we led the world, and it was operational efficiency rather than novelty of equipment that was the British achievement’

Winston S. Churchill: *The Gathering Storm*, Cassel, p122, 1948.

‘The British had, from the first, an extraordinary advantage, never to be balanced out at any time in the whole war: their radar and fighter-control network. It was for us and our leadership a freely expressed surprise, and at that a very bitter one, that Britain had at its disposal a close-meshed system, obviously carried to the highest level of current technique, which supplied the British Fighter Command with the most complete basis for direction imaginable … We had nothing like it …‘

General Adolf Galland, in E.G. Bowen: *Radar Days*, Hillger, p28, 1987.

Quoted at the beginning of *Making Vision into Power: Britain's Acquisition of the World's First Radar-based Integrated Air Defence System 1935 – 1941*, P.E. Judkins, PhD thesis, DCMT Shrivenham, 2007.

The cavity magnetron

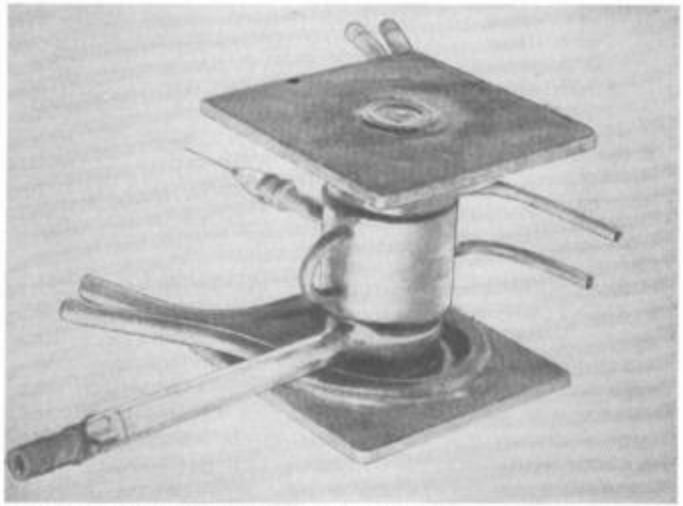
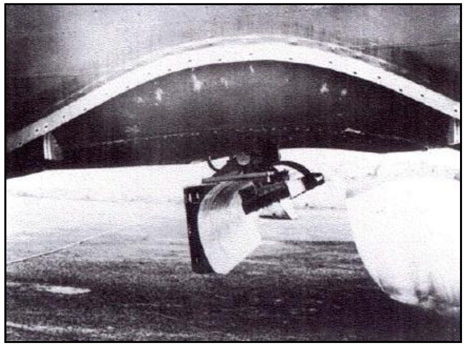
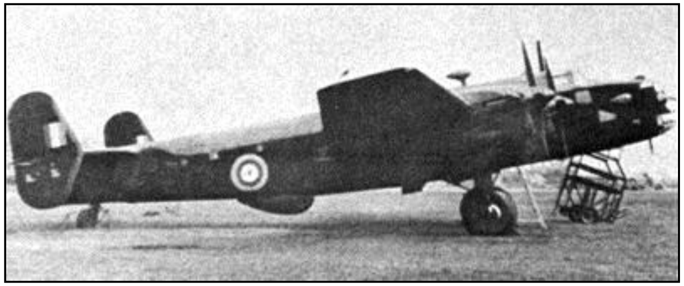


Fig. 19.7b *Anode block of first British 10cm magnetron*
GEC Journal of Research

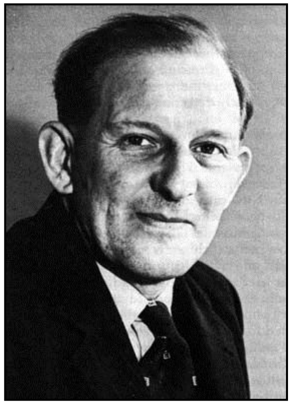
British Universities have a long and distinguished tradition of work in radar - the cavity magnetron was invented by Randall and Boot at the University of Birmingham in 1940.

H2S

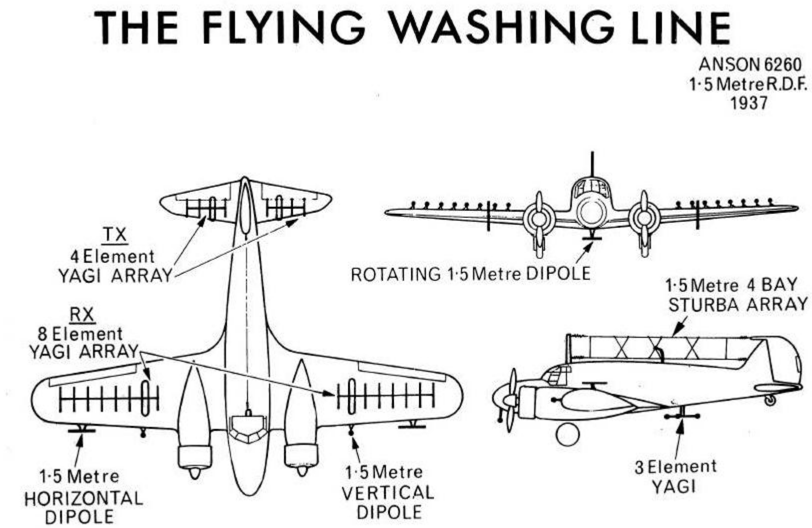


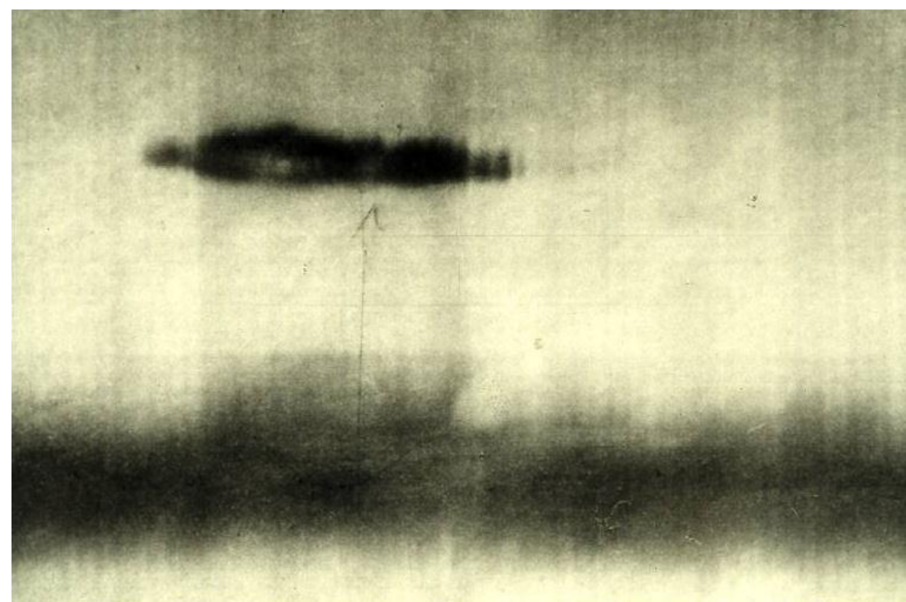



21/1. HQPFF. 20/21-12-43//19000' 347°T. 070°/15m. 30/20S M+G. 1935
FRANKFURT. F/L TOLCHARD. G/82



Air-to-Surface Vessel (ASV) radar





Naval radar

- Initial work at HM Signal School Portsmouth led to Type 79. Initially 75 MHz, then 40 MHz, with a prototype demonstrated in early 1938. By the end of the year the Type 79 had been installed on HMS RODNEY and HMS SHEFFIELD.

- Soon upgraded to Type 279. This used separate transmitting and receiving antennas mounted on their own masts but rotating in synchronization. The antennas were small, resulting in a wide beam which was adequate for detecting aerial intruders at ranges of up to about 80 km, but not so good at targeting naval vessels. Also not very good at picking up low-flying aircraft.

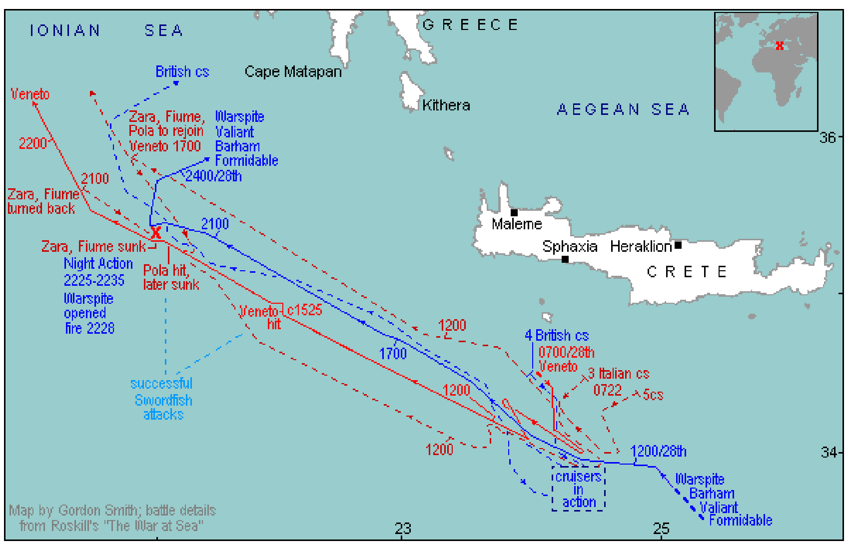
- The need for more precise targeting led Royal Navy researchers to hastily develop a 200 MHz radar, Type 286, based on the technology Bowen had developed during his AI work. The Type 286M could pick up a surfaced submarine at a distance of no more than a kilometre if the vessel carrying the radar was pointed in the right direction.

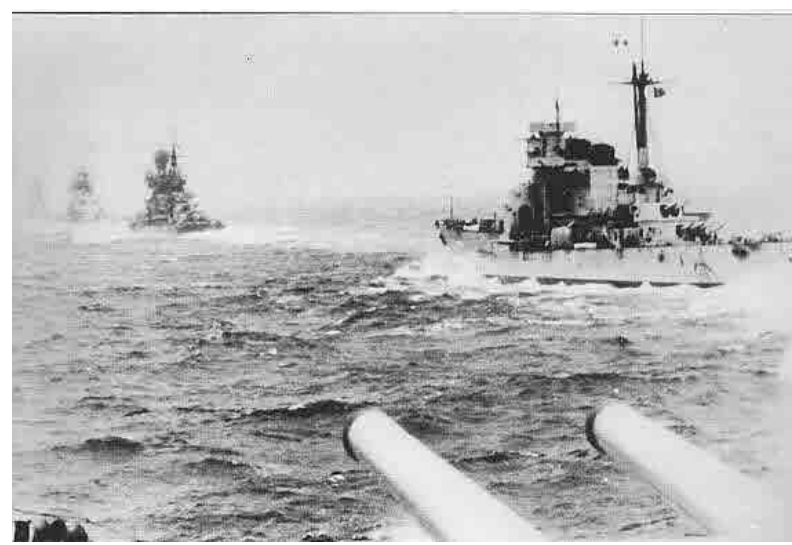
Greg Goebel, *The Wizard War: WW2 and the Origins of Radar*, http://www.vectorsite.net/ttwiz.html

Battle of Matapan: 27-29 March 1941

The value of radar to naval operations was proven when the British Mediterranean Fleet including the battleships HMS BARHAM, HMS VALIANT and HMS WARSPITE and the aircraft carrier HMS FORMIDABLE, as well as ships of the Royal Australian Navy, intercepted and sank or severely damaged a substantial Italian battle fleet off Cape Matapan. The allied fleet was commanded by Admiral Andrew Cunningham. The allied action relied heavily on Ultra intelligence decrypts from Bletchley Park.

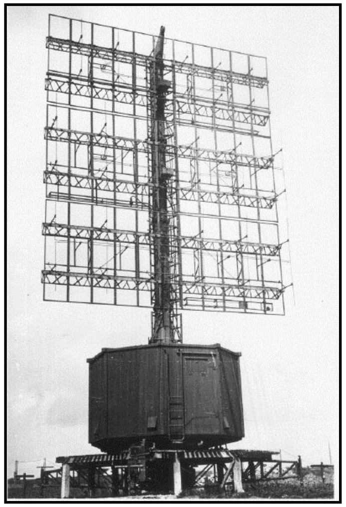
The final phase of the battle took place at night, and depended critically on radar detection of the Italian fleet.

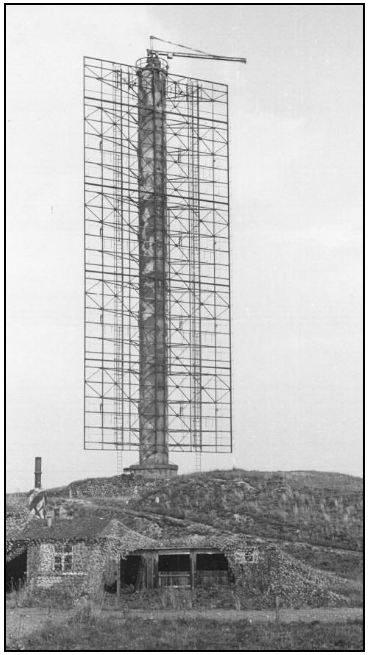


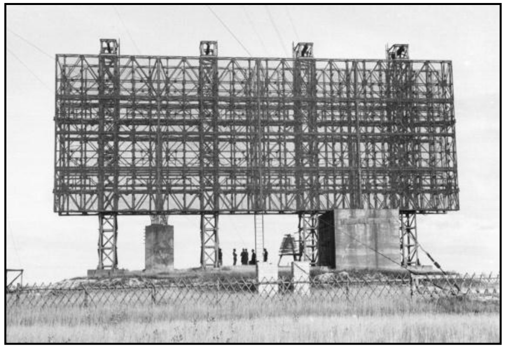


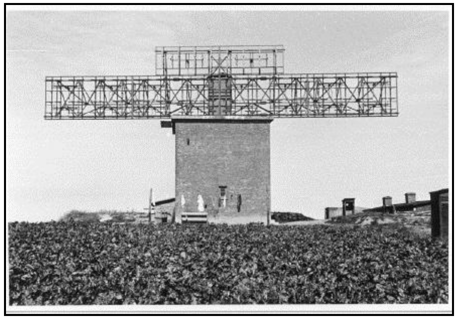
German air defence radars

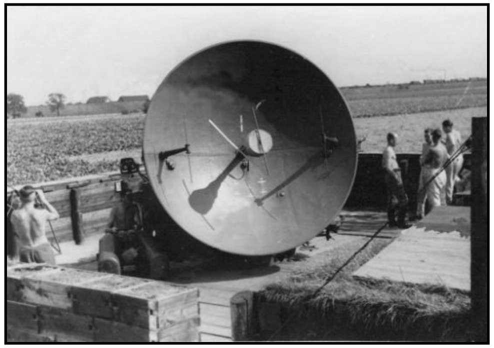
Freya, Wassermann, Mammut, Jagdschloss – early warning





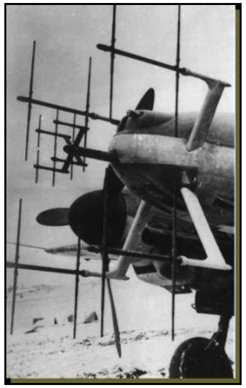




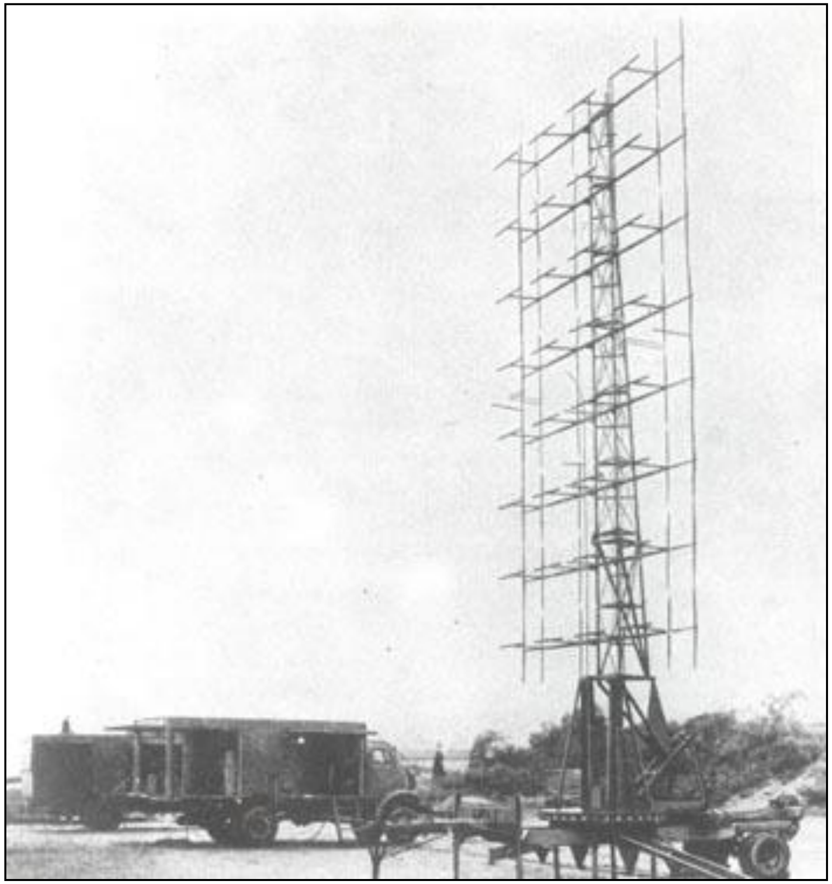


Würzburg – fighter control

Lichtenstein SN2 – AI



Early U.S. EW Radar: SCR-270



The name 'RADAR'

Copied from
Louis Gebhard
book on NRL
1979

UNCLASSIFIED

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ON ... (DATE) ... Signature of Custodian

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Three photostats made by Comdr ... for ... of "Radar" R ... 7/16/43.

From: Chief of Naval Operations
To: Chief of Bureau of Ships
Chief of Bureau of Aeronautics
Chief of Bureau of Ordnance
Director, Naval Research Laboratory
Chairman, General Board

Subject: Radio Detection and Ranging Equipment - Security Classification of and Approved Abbreviation for.

1. The type of radio equipment which has been developed under Special Project No. 1 and which has been referred to as "Radio Ranging Equipment", "Radio Detection Equipment", "Radio Echo Equipment", "Pulse Radio Equipment", etc., will hereafter be known as "Radio Detection and Ranging Equipment".

2. The detailed security classification of radio detection and ranging equipment is as follows:

(a) SECRET - The design of the equipment (other than the parts included in subparagraph (b)), the purpose for which the equipment is designed and the principles and methods of operation.

(b) CONFIDENTIAL - Those features which obviously cannot be kept secret, such as the design and installation of the antenna unit with its power elevating and training apparatus, the power supply for the equipment, the inter-connecting cables, and other items which do not disclose any information which is classified in subparagraph (a) as SECRET.

3. In order that radio detection and ranging equipment may be referred to in non-classified dispatches or correspondence (the contents of which do not violate the classifications in paragraph 2), and also in conversation, the use of the abbreviation "RADAR" is authorized.

4. The urgency of delivery of this document is such that it will not reach the addressees in time by the next available officer courier. The originator, therefore, authorizes the transmission of this document by registered mail within the continental limits of the United States.

H. R. STARK

60834 (382)

THE WORD "RADAR"

The word "radar" was coined from "radio detection and ranging," one of the titles used by NRL for this field of work, by LCDR F.R. Furth and LCDR S.M. Tucker, who shared in responsibility for the Navy's original procurement program. LCDR Furth (later RADM Furth) and LCDR Tucker (later RADM Tucker), while on duty at the Navy Department, devised the acronym and took action to put it into effect. The above letter, dated 19 Nov. 1940, signed by ADM H.R. Stark, then the Chief of Naval Operations, made the word official. Later, both LCDR Furth and LCDR Tucker, as Captains, became directors of NRL (CAPT Furth, 1949 to 1952; CAPT Tucker, 1955 to 1956). CAPT Furth became the Chief of Naval Research as ADM Furth (1954 to 1956). 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.

Honoured guests, Watson-Watt and Hülsmeyer, at a radar conference, Frankfurt, 1953

Courtesy of A.O. Bauer, 15 January 2005, The Netherlands

After reviewing Hülsmeyer’s 1904 invention, Watson-Watt stated,

I am the father of radar, whereas you are its grandfather.