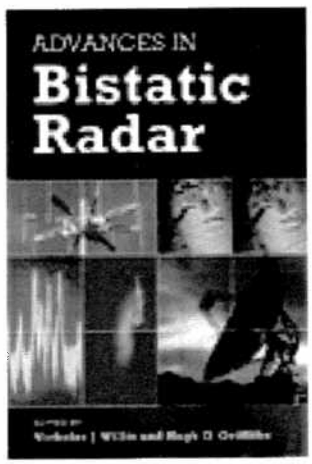
SI4000 Fall AY2008
Systems Engineering Colloquium
In Conjunction with IEEE

Thursday November 01st , 1500, SP 321

"Bistatic Radar Systems"



Nicolas Willis
Author/Consultant

ABSTRACT

As usually happens during the ongoing development of a major invention, old information is released (or declassified) and new information surfaces. Such is the case with radar, in particular the first radar, Christian Hulsmeyer's 1904 telemobilskop, and then the "re-discovery" of radar in its bistatic configuration in the 1930s.

This new information is summarized, including the multiple claims of invention, which lead the great radar pioneer Lamont Blake to comment that "radar is one of those bastard inventions: one mother, many fathers." Speculation about the utility of radar had it been embraced earlier closes the brief.

RADAR HISTORY UPDATE

---NEW AND ILLUMINATING INFORMATION ON THAT "BASTARD INVENTION"

NICHOLAS J. WILLLIS

- OFFER INCREMENTAL DATA TO UPDATE THE HISTORY OF . . .
- DO A LITTLE "SHOW & TELL"

A LITTLE BACKGROUND - 1

- Virtually all radar discoveries in the 20's and 30's were bistatic
  - Moving vehicles cutting an RF comm beam
  - But always with a nod to those eccentric (1904) *telemobilskop* tests

- Consequently, early 1930 radar air surveillance used
  - Bistatic fences
  - Psuedo-monostatic radars using separate antennas

- Then pulsed waveforms and the duplexer enabled single antenna monostatic radars for air surveillance

- Finally, the magnetron enabled fire-control operation

- All of which were used in WW II

THIS DATA IS WELL DOCUMENTED — SKOLNIK (WILLIS) elaborate & show book 2

A LITTLE BACKGROUND – 2

THEN NEW INFORMATION APPEARS:

- New book or lecture triggers a memory, yielding old photos, data or recollections
- Further research surfaces, for example:
  - D. Prichard: "The Radar War: The German Achievement…"
  - P. David: "Le Radar"
  - Y. Nakagawa: "Weapons of World War II"
  - B. T. Neal: "CH---The First Operational Radar"
  - V. S. Chernyak: "Radar in the Soviet Union and Russia…"
  - A. O. Bauer: "Christian Hülsmeyer…"
  - M. Svejgaard: "The Klein Heidelberg"
- Finally, old information is released or declassified

AND THIS IS WHAT I WILL COVER TODAY

A LITTLE BACKGROUND – 3

So why the title "Bastard Invention" ?

Many of these early radar researchers and developers claimed to have invented radar

I was commenting about these claims to a TSC colleague, Lamont Blake, when he observed:

"Ah, another one of those bastard inventions: one mother and many fathers"

PS: I must nominate Lamont as "the father of the definitive radar range equation"

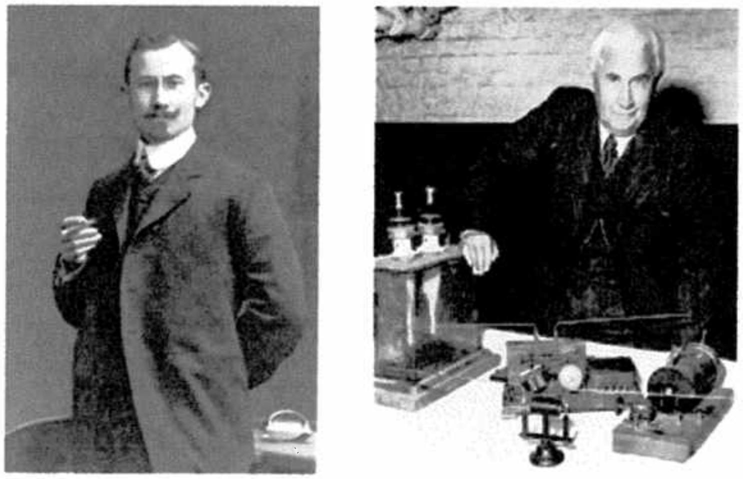
codified —
embraced by Barton —

AGENDA

- PART 1 Hülsmeyer Legacy (1904)
  - Invention
  - Demonstrations
  - *What-ifs*
- PART 2 Re-discoveries (1922 – 1937)
  - Communications links → Radar fences
  - Monostatic radar evolution
  - Klein Heidelberg
- PART 3 Claims
  - Russian entry
  - The Denouement

CHRISTIAN HÜLSMEYER AND HIS TELEMOBILSKOP

courtesy of University College London



Christian Hülsmeyer and his telemobilskop. The spark gap transmitter is on the left; receiver, dipole antennas and bell on the right. Left photo was taken in 1904; right photo, considerably later. The telemobilskop is now on display at the Deutsches Museum, Munich

2 [illegible] pictures

3 Close-up [illegible] RX

4 Ship [illegible]

5 Reaction

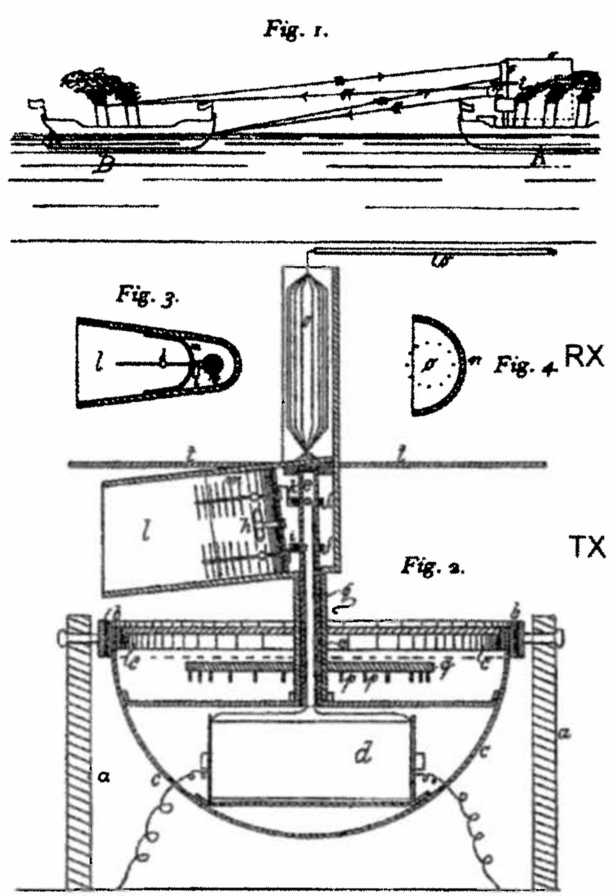


Figure 5

On 30 April 1904 Hülsmeyer applied for a patent for his epoch-making **Telemobiloskop**.[66] In spite of the many promising reactions, it nevertheless finally failed to become a commercial success. This did not stop him applying, shortly thereafter, in other European countries for equal patents as well.[67] Let us follow the course of the circumstances of these, intriguing, early days of radar.[68]

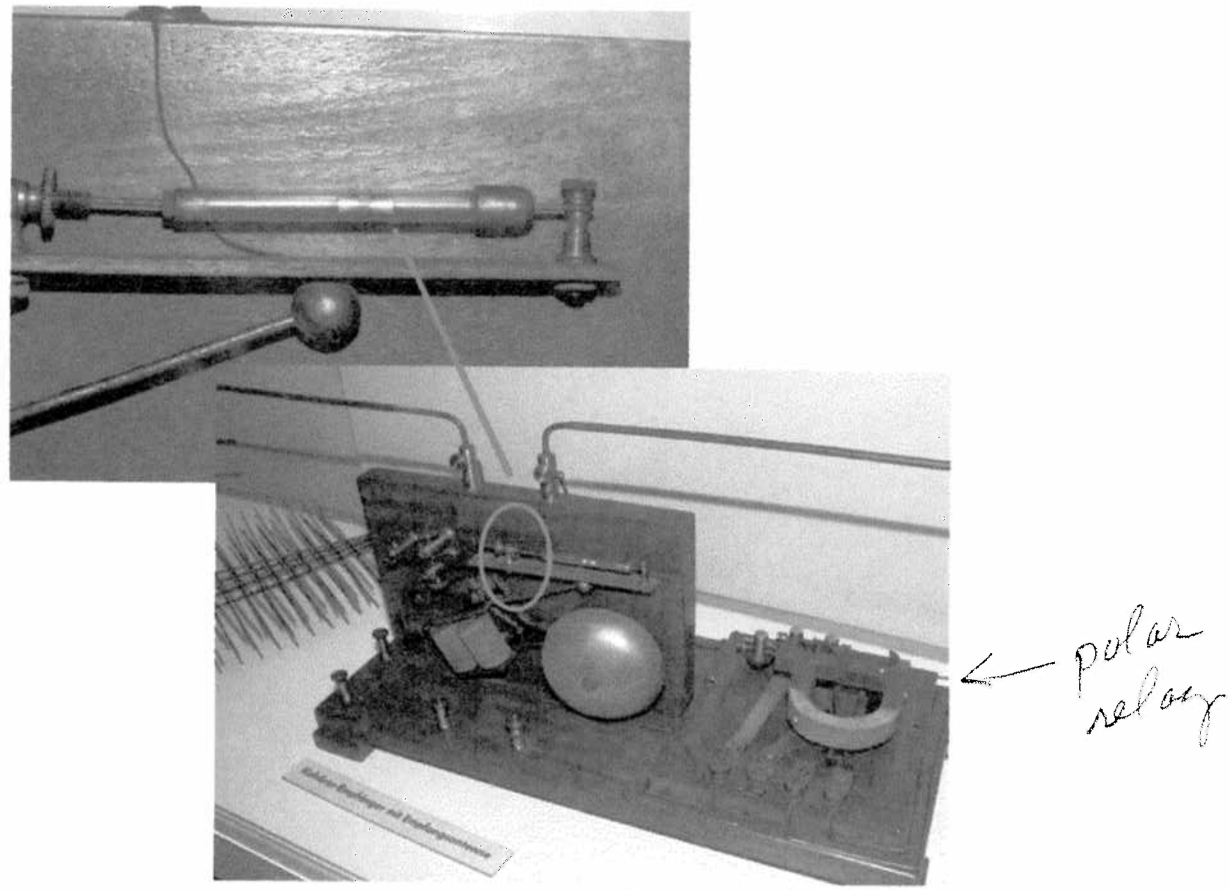
On this occasion, we follow Hülsmeyer's pretensions as these had been worded in his British patent specifications applied for on 10 June 1904. This was remarkably quickly granted with GB13170, on 22 September of that year.[69]

Its genuine specification (claim) was:

Herzian-wave Projecting and Receiving Apparatus Adapted to Indicate or Give Warning of the presence of a Metallic Body, such as Ships or Trains, in the Line of Projecting of such Waves.

reflector behind it. We recognise that the receiving unit was shielded from the RF power parts by a metallic plate.

The received signals were transferred to the target detector in the bottom part of the telemobiloscope. Since no low noise amplifier was available at that time, Hülsmeyer used a device well known at those days, called "Coherer".



WHAT DID THE INITIAL TESTS SHOW?

- DETECTION AND DOA OF SHIPS 2 – 3 KM (POSSIBLY UP TO 5 KM) ON THE RHINE RIVER IN 1904
  - FROM THE RHINE BRIDGE
  - ON THE SHIPS-TENDER COLUMBUS

- BUT NO RANGING DATA
  - HÜLSMEYER RECOGNIZED THIS LIMITATION AND DESIGNED ---BUT NEVER TESTED---TWO COARSE METHODS FOR ESTIMATING RANGE

Let us continue with the course of history: -
We know from Wierdsma's letter that he invited Hülsmeyer to demonstrate his ship-colliding-prevention-apparatus during a tour through the harbour of Rotterdam on board the ships-tender Columbus.[114]

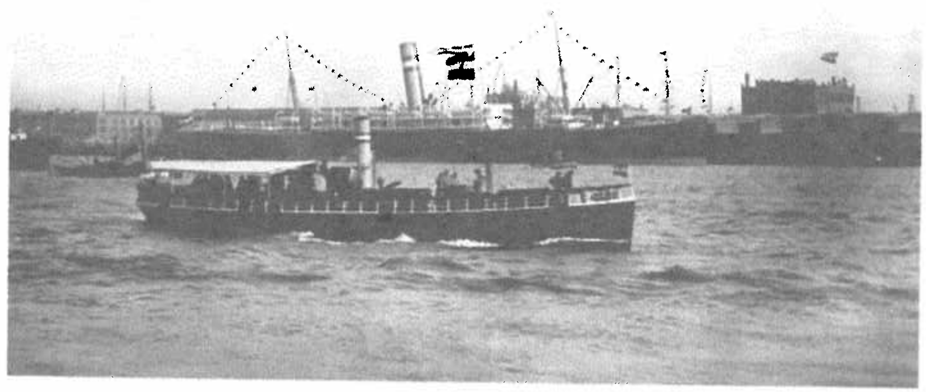


Figure 16

We may assume that Hülsmeyer first introduced himself and his apparatus to the audience of technical ship experts with an introductory talk. What did he tell these laymen? That we don't know, but he, certainly, handed out a leaflet which is shown below.[115]

Briefly the leaflet (see next page) explained that his apparatus aims to detect, by means of EM waves (wireless), ships at distances of three to five kilometres. He regards it as a kind of electrical eye. The basic principle relied upon reflection. In this case not by the reflection of visible light, but by reflection of electrical waves. Which respond in a similar way to light rays

REACTIONS to the 1904 TELEMOBILSKOP TESTS

- MILITARY
  - Germany: "Not interested; my people have better ideas."
    ---Adm. Von Tirpitz
  - Britain: Rejected (NIH problem)

- COMMERCIAL AND SHIPPING
  - Shipping companies impressed and enthusiastic
  - But no orders!
    - Tight funding
    - Wireless telegraphy (both comm and DF)

THEN DISASTER ON LATER TESTS

- A LONGER-RANGE VERSION OF THE TELEMOBILSKOP WAS TESTED AT THE HOOK OF HOLLAND
- THE TESTS WERE DECLARED A FAILURE APPARENTLY CAUSED BY "NEW" RFI:
  - RESTRICTIONS ON TRANSMITTER
  - EFFECTS ON RECEIVER
- AT THIS POINT HÜLSMEYER ABADONED THE TELEMOBILSKOP FOR OTHER COMMERCIAL WORK
- NEVERTHELESS ALL ELEMENTS OF A RADAR HAD BEEN "REDUCED TO PRACTICE":
  - Transmitter
  - Antennas
  - Receiver
  - Indicators

RANGEFINDER in MAINTOP of
USS NORTH DAKOTA, circa 1910

The rangefinder is the long, horizontal tube in front of the seamen standing on the platform at the head of mainmast, in this case built as a cage-mast. It consists of lenses, reflectors and prisms at each end and center of the tube, which display two target images, one above the other, to an observer at the center. The observer aligns the two images with a vernier calibrated in range, solving the triangle with target at the apex. The range is then phoned to the fire-control station below. The observer also reports subsequent shell splashes as *short* or *over* the target. The system operated only in daylight and fair weather. It (and the seamen) was also handicapped by stack-gas (background) and gunfire-smoke (foreground). Rangefinders remained on most US warships until well after WW II. It was not one of the coveted battle stations. The addition of radar---when it was working---rectified all these problems. Photo courtesy US Navy.

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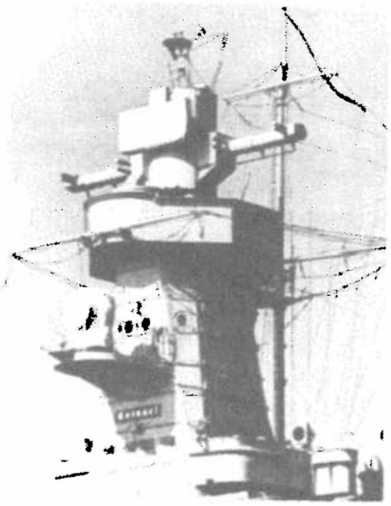
RANGEFINDER in a FIRE CONTROL TURRET on the ADM. GRAF SPEE, 1939 (with a FuMO 22 SEETAKT 400 MHz monostatic radar)



Optical rangefinder, still in a tube configuration but now much larger and with the operators encased in a turret, on the German pocket battleship *Admiral Graf Spee*, 1939 [5]. The 3 x 6 m antenna covered by canvas just above the rangefinder is the *FuMO 22 Seetakt,* a 361-429 MHz monostatic radar used for both air defense and gunfire control. The latter was useful up to 20 km with a range accuracy of about 70 m and a direction finding accuracy of 3 degrees. Data from the radar and the optical rangefinder were readily compared. Early versions of these radars often failed after a few salvos from the main batteries, which violently rattled the ship. A modified version of *Seetakt* was installed on the *Bismarck* but apparently not on the *Tirpitz*, which apparently remained satisfied with optical rangefinders. Photo courtesy of Fritz Trenkle [5].

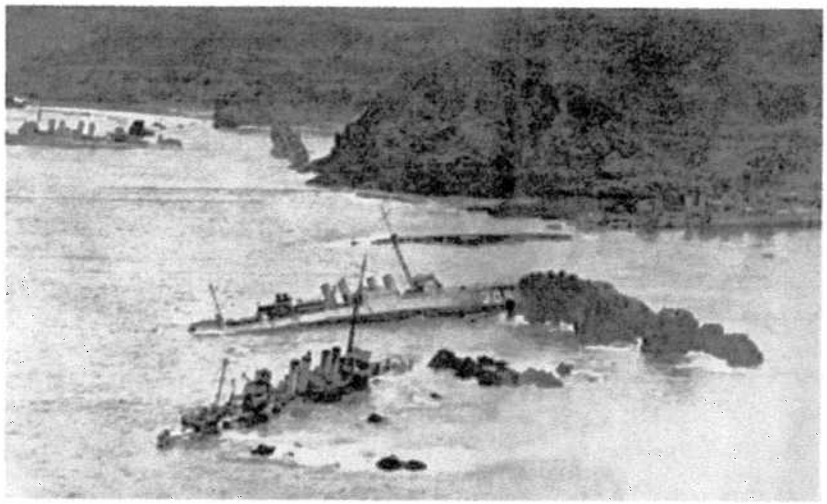
Now show STADIMETER

DISASTER AT HONDA, SEPTEMBER 8, 1923

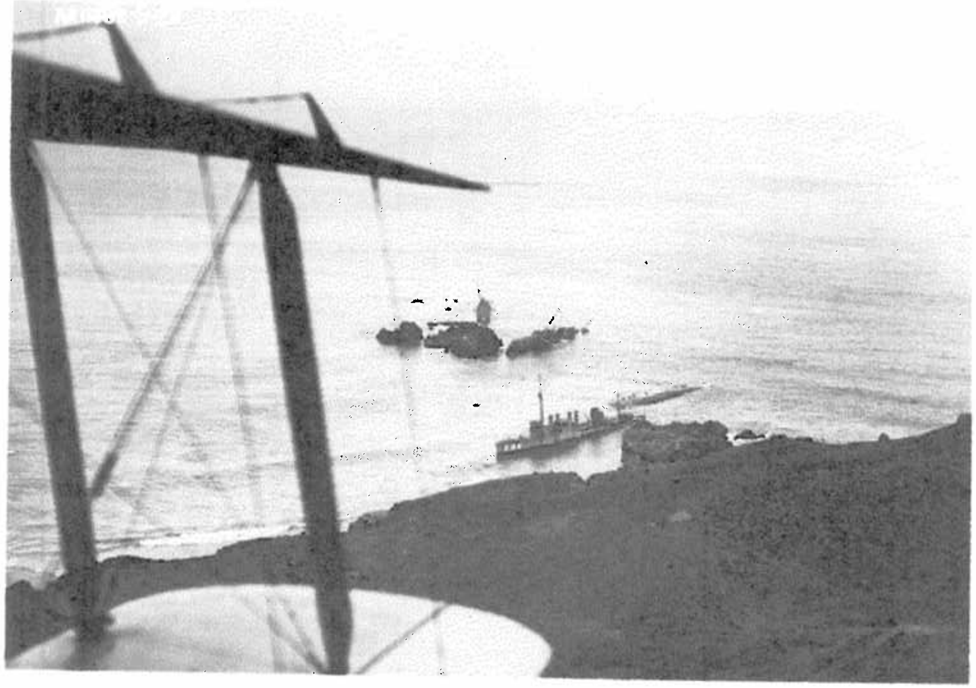
- SEVEN, 1200T USN DESTROYERS RAN AGROUND OFF HONDA, 10 MI NORTH OF PT ARGUELLO
- 23 SEAMEN DIED
- MATERIAL LOSS WAS >$13M (~$200M TODAY)
- IN A PERIOD OF 5 MIN THE USN LOST MORE COMBATANT SHIPS THAN TO ENEMY ACTION DURING WW I
- WHY? FOG, DEAD RECKONING + FAULTY DF

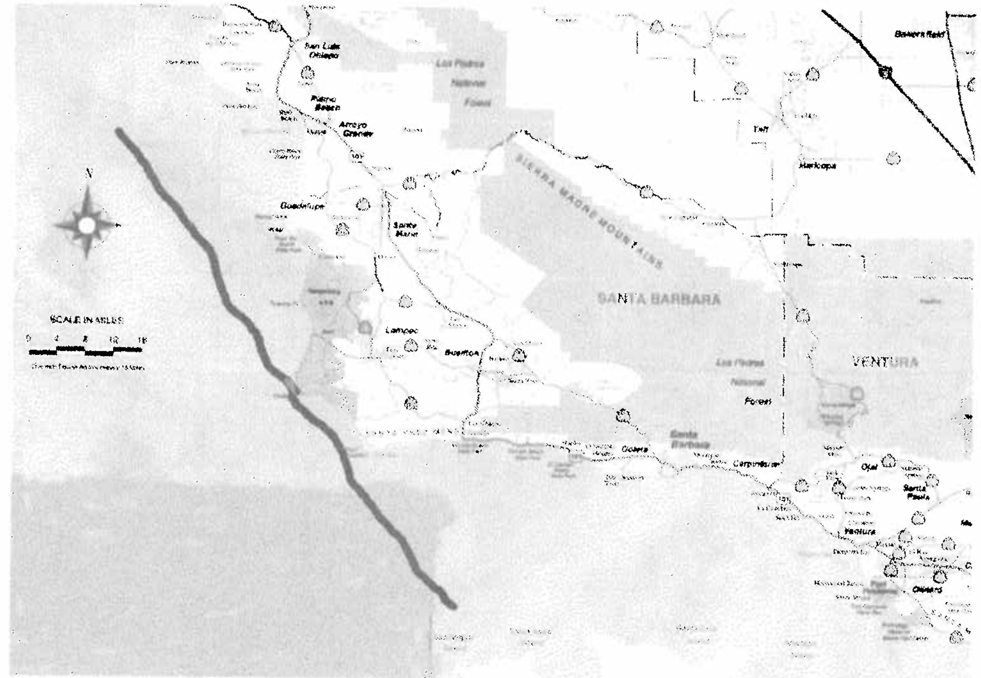
PRICHARD → TITANIC

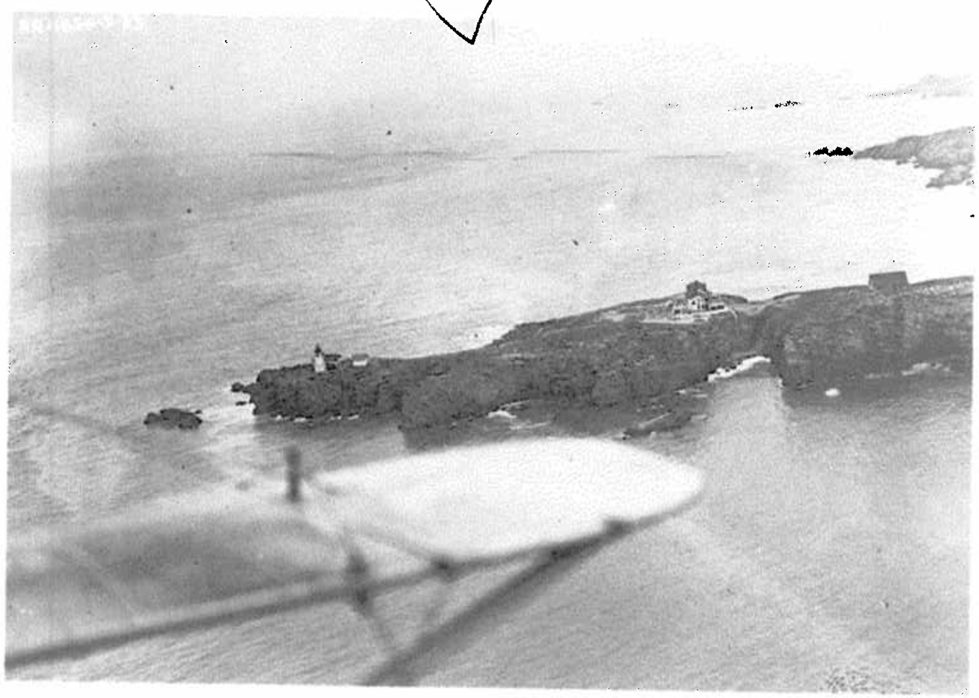
DISASTER AT HONDA, SEPTEMBER 8, 1923

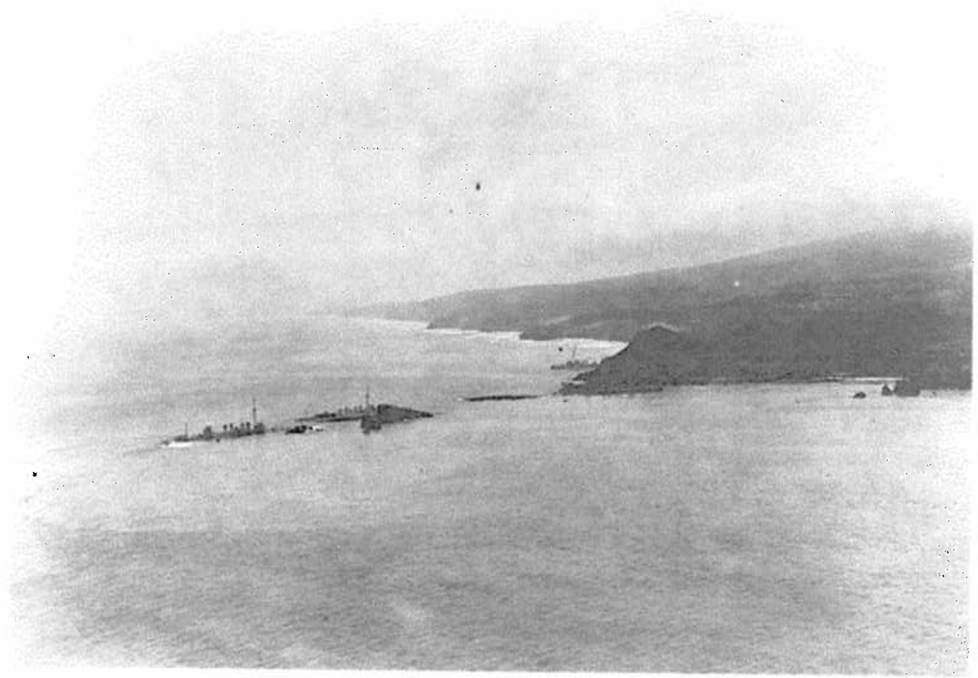


Seven, 1200 ton US destroyers on the rocks off Honda, ten miles north of Pt. Arguello, California, September 8, 1923. Five destroyers are aground but upright; two have capsized. Twenty three seamen died. In a period of five minutes the US Navy lost more combatant ships than she had lost by enemy action during WW I. Material loss was over $13M, or roughly $200M in 2006 US currency. Photo courtesy of the US Navy. Information courtesy of *Ships and the Sea* [7].




SANTA BARBARA
VENTURA
SIERRA MADRE MOUNTAINS
SCALE IN MILES
N





BASIC FUNCTIONS FOR SUCCESSFUL RADAR OPERATION

1. INSTALLED
2. WORKING
3. TURNED ON
4. MANNED
5. DETECTED
6. REPORTED
7. HEEDED

RECALL THE DEC 7, 1941 SCR-270 INCIDENT AT PEARL HARBOR

SO THE RADAR WORLD HIBERNATED FOR THE NEXT 20 YEARS

EARLY BISTATIC RADAR DISCOVERIES
---Part 1

Country	Engineers	Date	Transmitter	Target	Results
US (NRL)	Taylor, Young, Hyland	1922 - 1936	Communications Landing Beacons Radio Stations	Ships Aircraft Dirigible	Forward scatter [F-S] & beat frequency [B-F] Rejected by USN Patent in 1934
UK	Appleton, Barnett	1924 - 1925	BBC station at Bournemouth	Ionosphere	B-F detection with stepped frequency waveform for ranging
US	Breit, Tuve	1925	Station NKF, Washington DC	Ionosphere	1 ms pulsed waveform for ranging
UK (PO)	Nancarrow, et al	1932	Communications	Aircraft	B-F detection Reported but overlooked
US (BTL)	Englund, et al	1933	Communications	Aircraft	First widely published B-F report (IRE)
France	David	1933	Own design	Aircraft	Predicted in 1928 Then read BTL paper Deployed ~20 F-S fences in 1938

SAME REASONS

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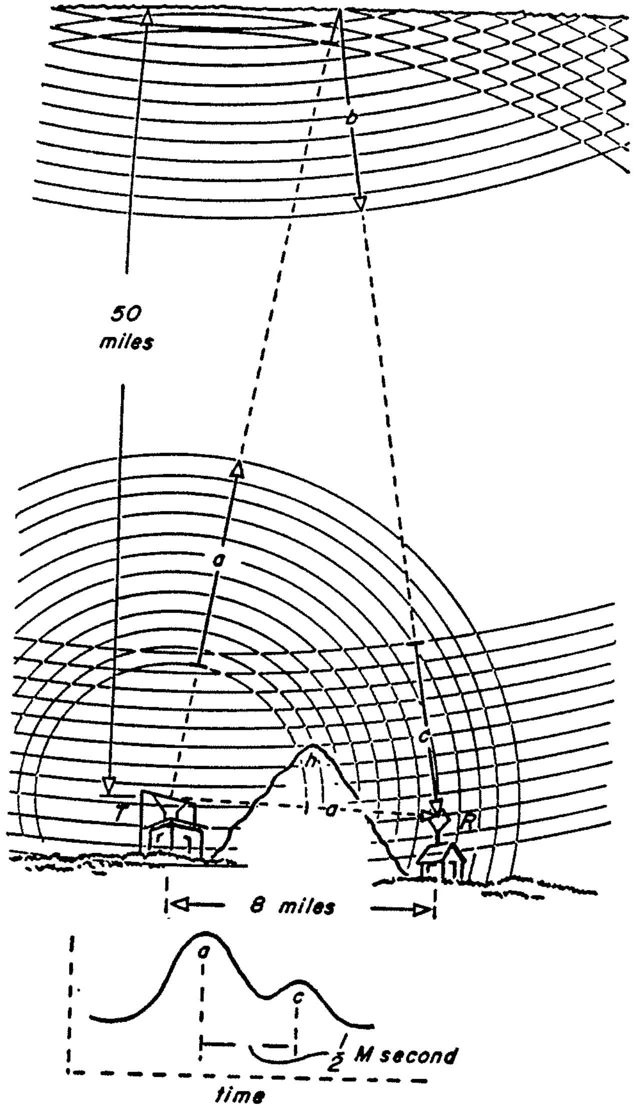
Between 1922 and the start of WWII the "radar effect" was re-discovered by many engineers, primarily when they conducted nascent communication propagation experiments and a target (ship, aircraft, steam roller) cut the communications beam. Both forward scatter and beat frequency effects were observed, often together. These observations started a frenzy of activity to confirm and exploit the effect. It also started the publications war---and of course claims of invention.



Geometry for 1925 Breit and Tuve Ionosphere Experiments, where T is the NRL transmitter, R is the receiver at the Department of Terrestrial Magnetism, and partially shielded from the transmitter by a hill, h, and I is the ionosphere (Ref. 163)

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Nov. 27, 1934. A. H. TAYLOR ET AL 1,981,884

SYSTEM FOR DETECTING OBJECTS BY RADIO

Filed June 13, 1933 3 Sheets-Sheet 1

FIG. 1

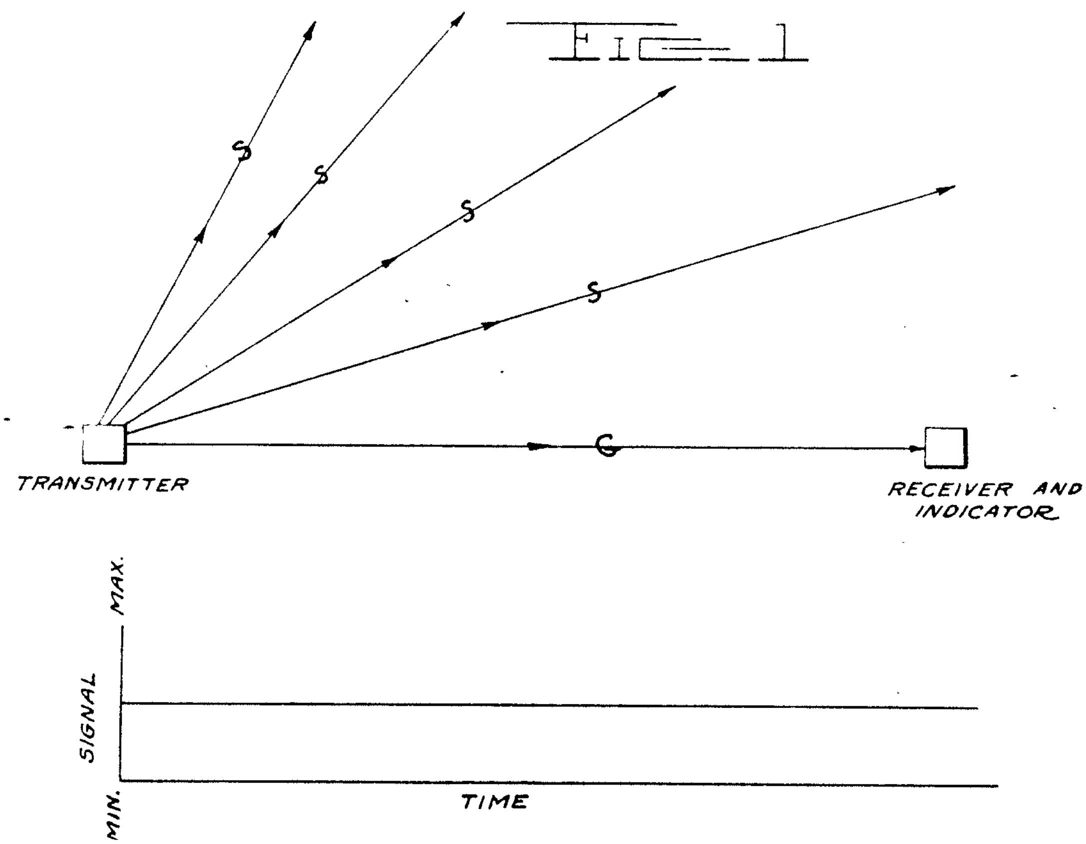
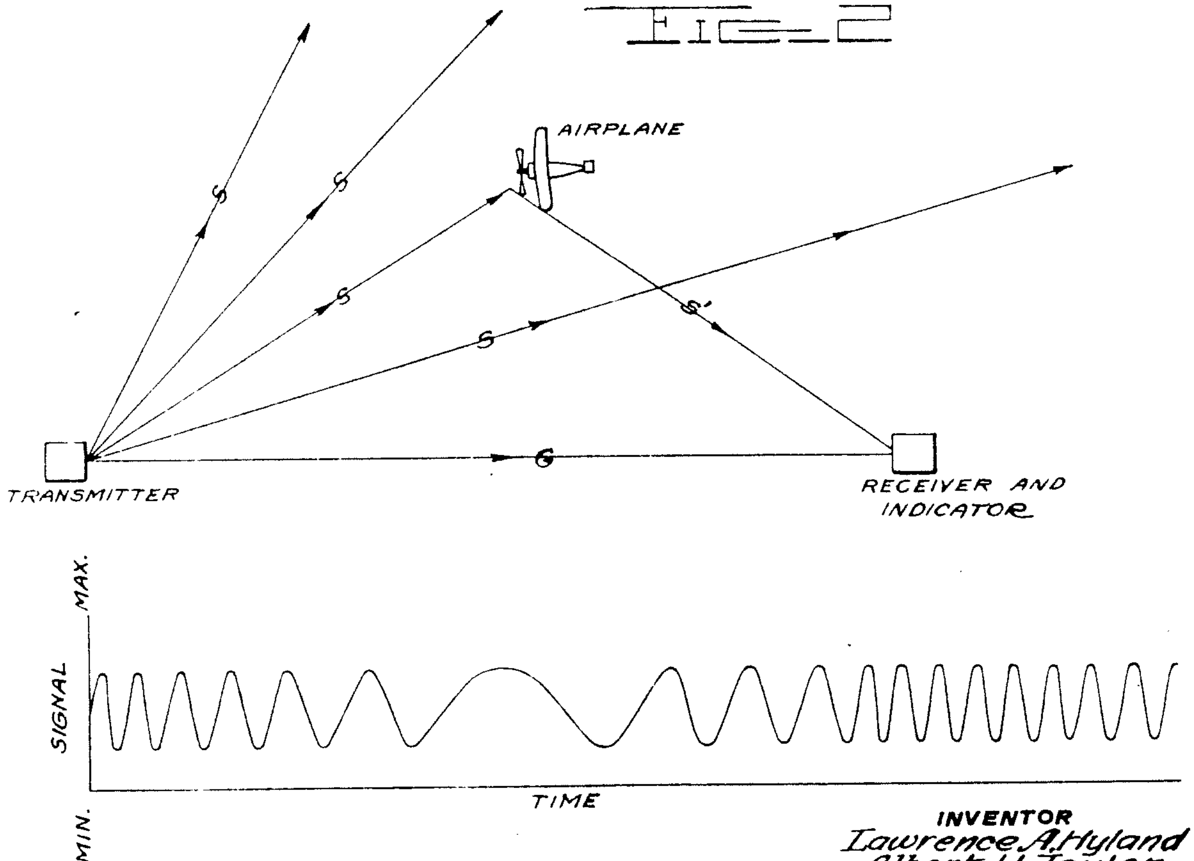


FIG. 2



INVENTOR
Lawrence A. Hyland
Albert H. Taylor
BY Leo C. Young
Robert A. [signature]
ATTORNEY

FIG. 6

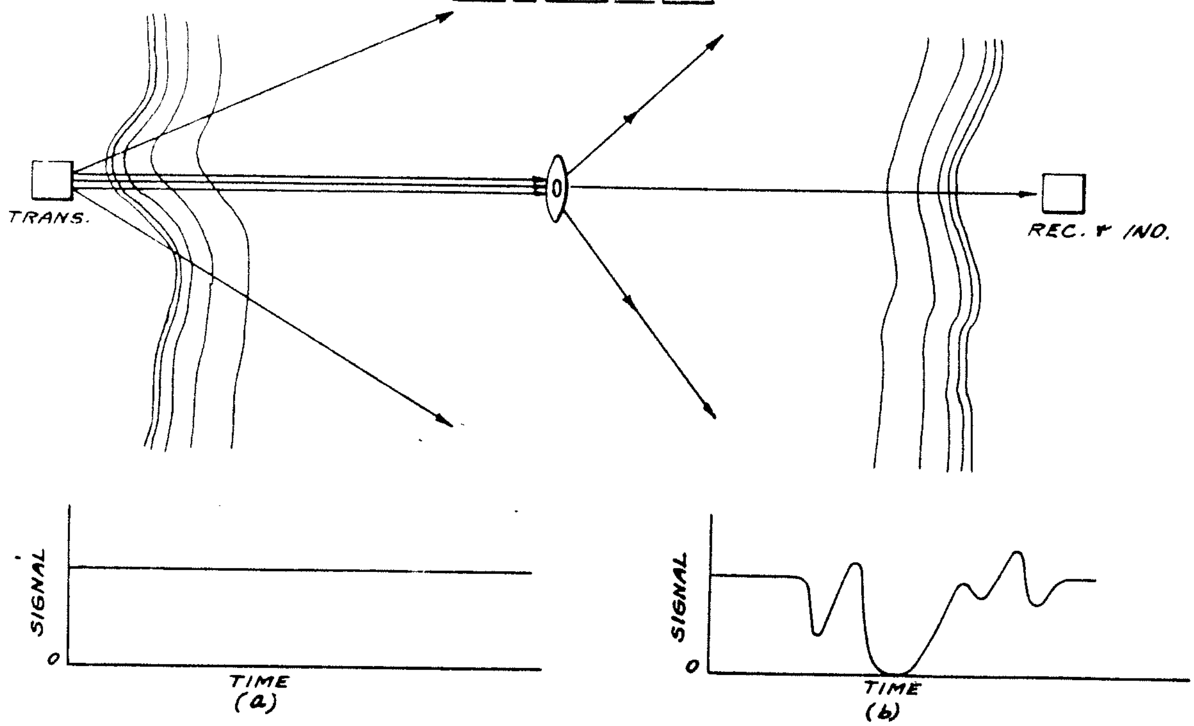
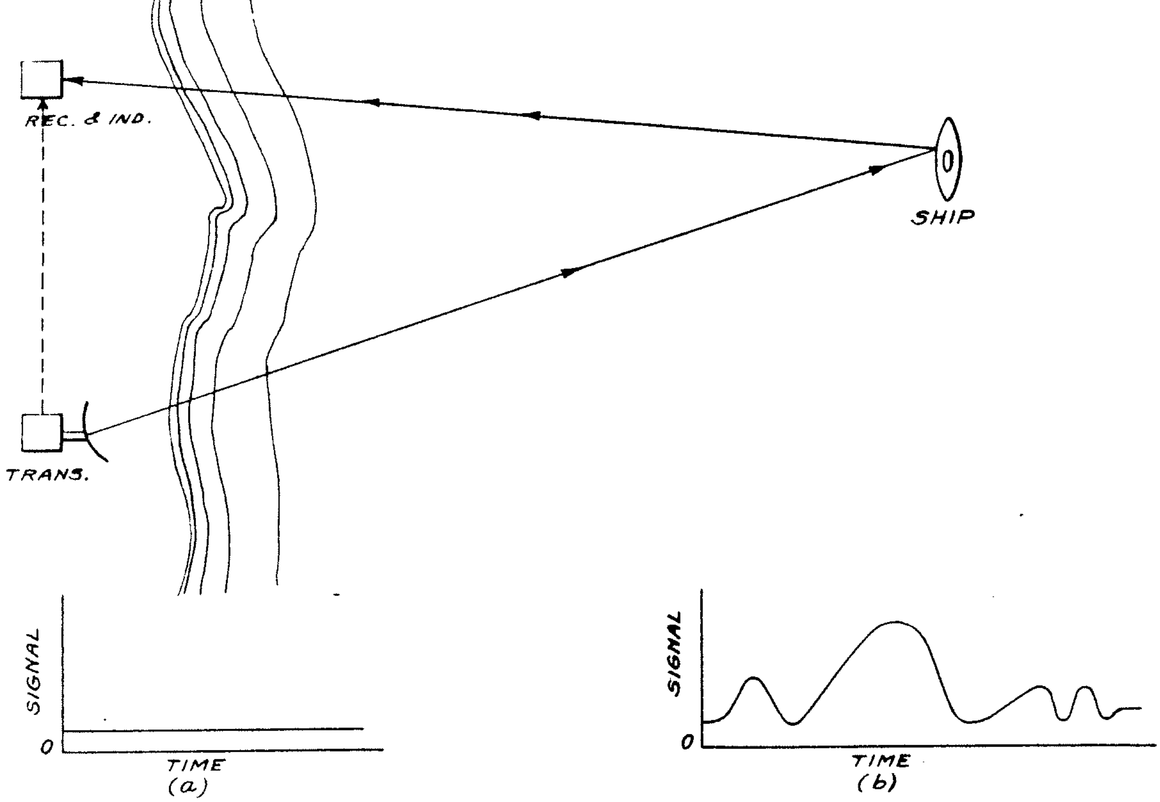
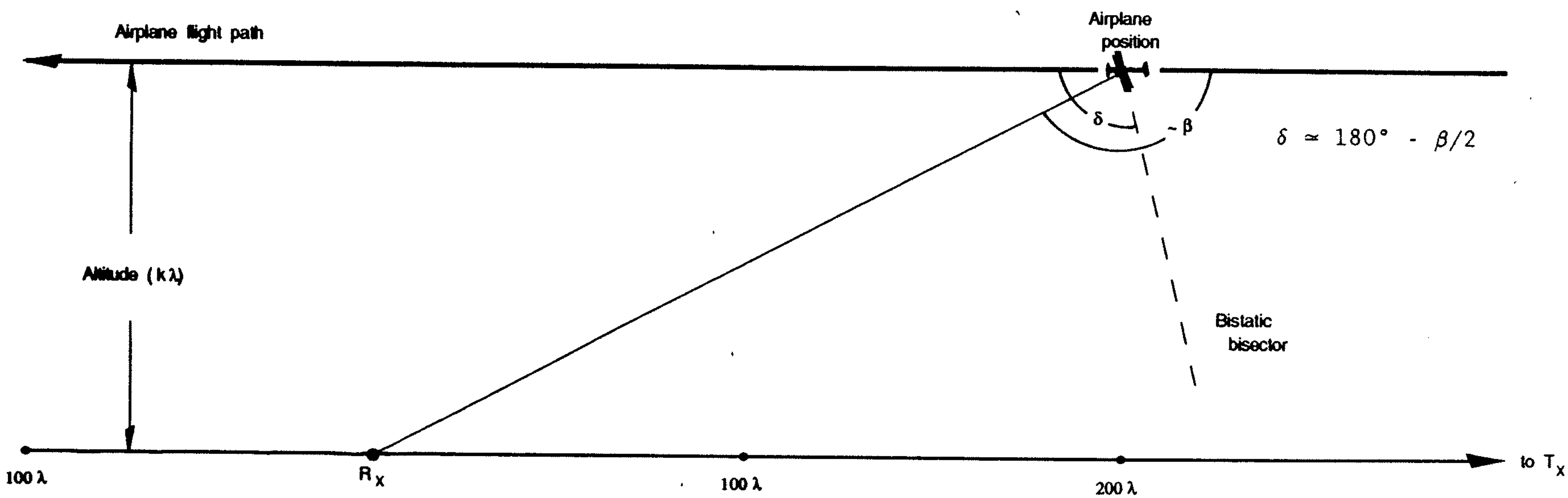


FIG. 5





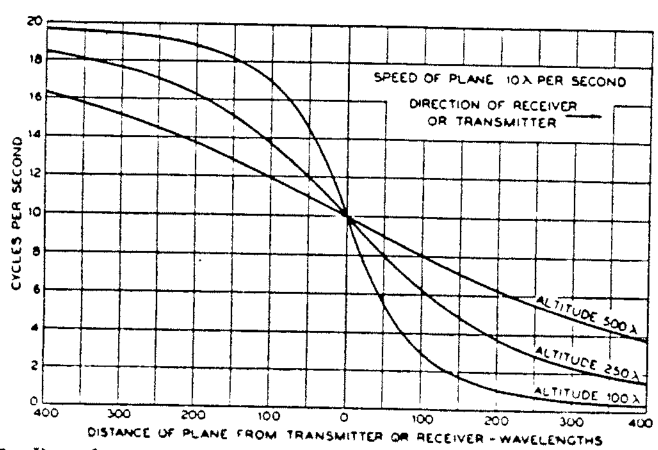


Fig. 7—Beat frequencies produced by reflection from a moving airplane.

$$f_{Tgt} = (2V/\lambda) \cos \delta \cos (\beta/2)$$

$$f_{Tgt} = \frac{2V}{\lambda} \cos^2(\beta/2)$$

$$|f_{Tgt}| \simeq 20 \cos^2(\beta/2)$$

From: **Englund, Crawford and Mumford, "Some Results of a Study of Ultra-Short-Wave Transmission Phenomena," Proc. IRE, Vol. 21, No. 3, March 1933.**

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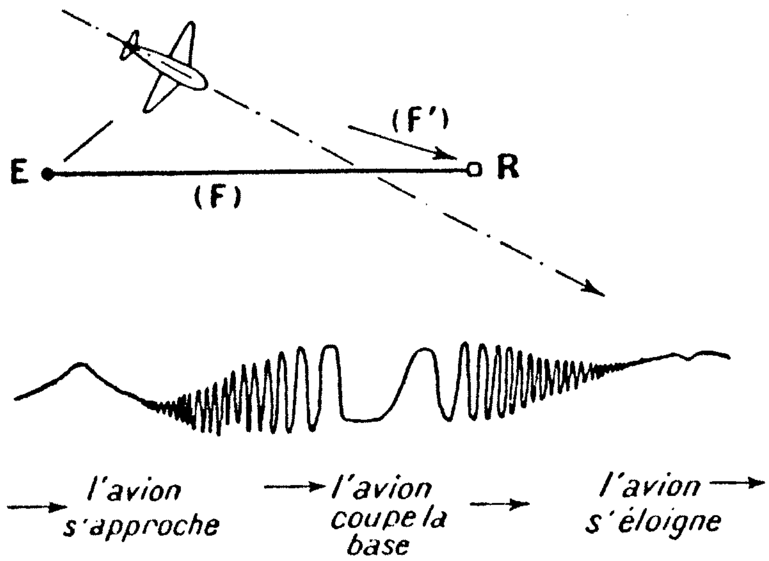


Fig. 26. — Passage d'un avion sur un « barrage E. M. » (*enregistrement de l'auteur*, 1937)

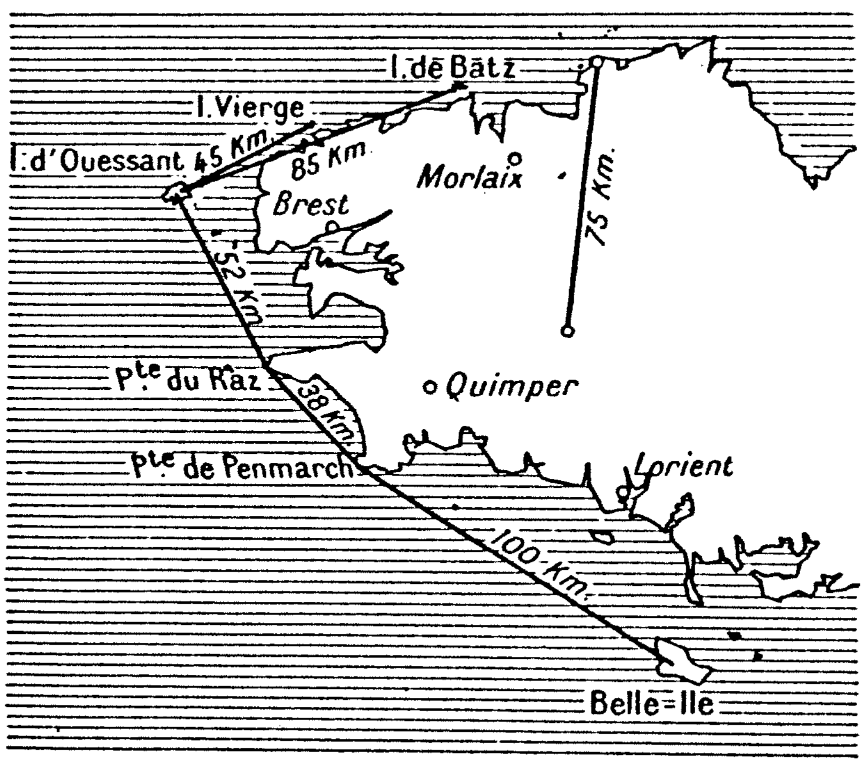
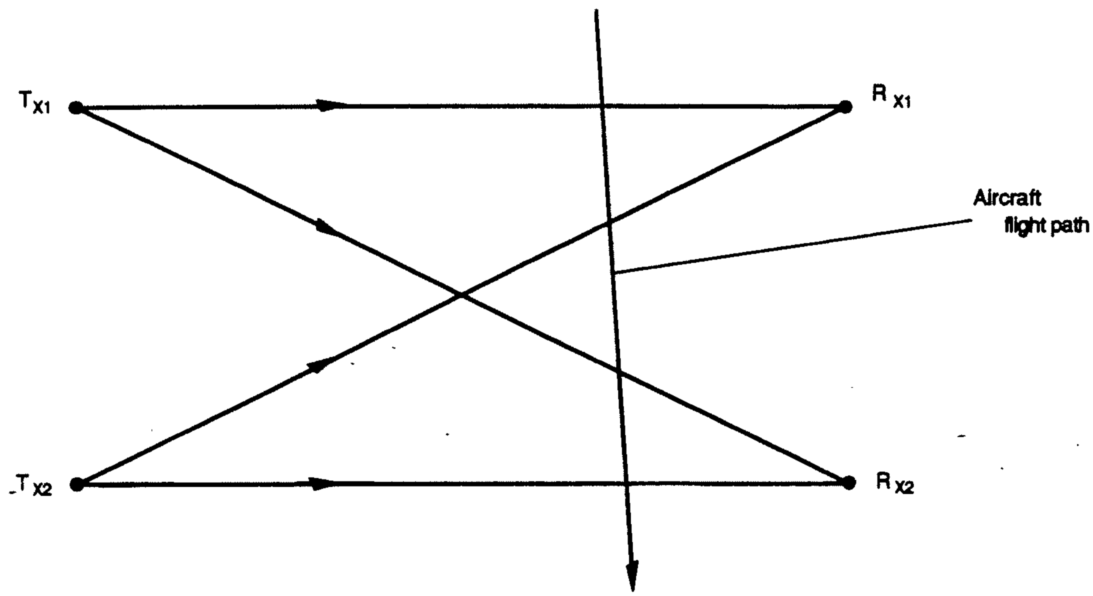


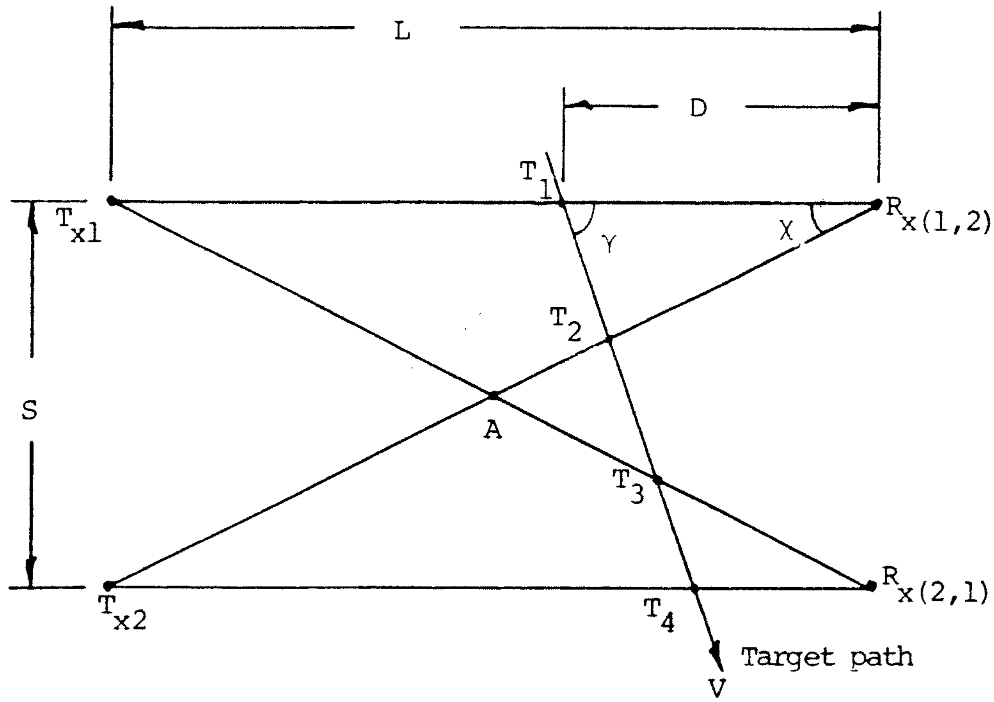
Fig. 1. — « Barrages électromagnétiques » protégeant Brest en 1939

From: **Pierre David, Le Radar, Presses Universitaries de France, 1949 (5th Ed., 1969).**



"ONE POSSIBLE "MAILLE EN Z"

CONFIGURATION: THE "DOUBLE Z"



Geometry for "double Z" grid of forward scatter trip wire fences.

$$\gamma = \tan^{-1}\left(\frac{\Delta T_2 \tan\chi}{\Delta T_1 - \Delta T_3}\right)$$

$\Delta T_1 = T_2 - T_1$

$\Delta T_2 = T_3 - T_2$

$\Delta T_3 = T_4 - T_3$

$$V = \frac{S \csc\gamma}{\Delta T_2(1 - \operatorname{ctn}\gamma \tan\chi) + 2\Delta T_1}$$

$$D = \cos\gamma \quad [S + V\Delta T_3(\tan\gamma \operatorname{ctn}\chi - 1)]$$

$$\tan\chi = S/L$$

EARLY BISTATIC RADAR DISCOVERIES
---Part 2

Country	Engineers	Date	Transmitter	Target	Results
Italy	Marconi	1933	Microwave telephone link	Steamroller Autos	F-S detection Awaited mono radar
Germany	Kühnold (J. Ender, EUSAR 02)	1934	Decimeter radio	Ship	B-F detection Reverted to mono radar, evolving into **FREYA** Patent app. rejected !
USSR	Oschepkov (Jailed in Great Purge)	1934	Own design	Aircraft	F-S detection Deployed ~45 ***RUS-1*** fences starting in 1939
UK	Wilkins, Watson-Watt	1935	BBC station at Daventry (GSA)	Aircraft	F-S detection plus AOA Evolved into ***Chain Home Radars*** Patent in 1935
Japan	Okabe, Yagi, Satake, Kobayashi	1936-1938	NEC (Sumitomo) design, not specified	Aircraft	B-F detection Built 400-500 fences Deployed >100 ***Type A*** fences starting in 1941

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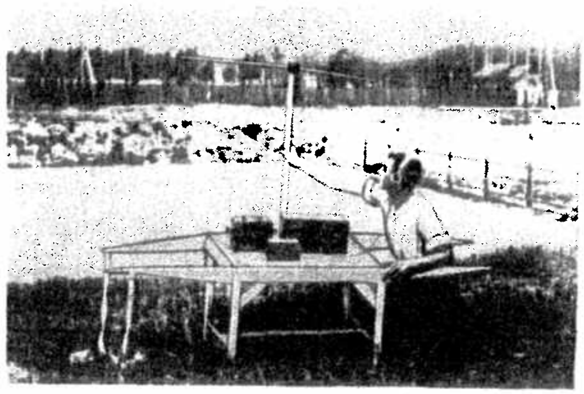
These bistatic radars were typically configured as fixed, ground-based fences to detect the presence of aircraft as they crossed the fence, which could then alert and cue air defenses. The problem of extracting target position along the fence could not be solved since range estimates become indeterminate (and target doppler approaches zero) on the fence. One Japanese **Type A** fence stretched from Formosa to Shanghai, ~800 km. However David (France) found a way to estimate the target state by overlapping the fences in a *maille en Z* configuration.

PHOTO OF THE **RAPID** BISTATIC RECEIVER
from P. K. OSHCHEPKOV'S "LIFE AND DREAMS,"
MOSCOW WORKER, 1967



из приемных устройств опытной аппаратуры радиообнаружения самолетов (лето 1934 г.)

Caption is translated as: *Experimental equipment from an airplane radio reception and detection device (Summer 1934).* Aircraft were detected by a doppler beat note in the headphones. The equipment had a baseline range of 11 km and could detect aircraft at 1-km altitude, 3 km from the receiver. Later tests established that 75-km ranges were possible. Subsequently five factory-produce experimental sets, called **REVEN (RHUBARB)** were produced. Then all worked after Oshchepkov was imprisoned. In 1938, work was restarted and 45 RUS-1 sets were produced using a 35-km baseline. Many were deployed to the Soviet far East and Trans-Caucasus starting in 1939.

BBC transmitter (right), Handley Page Heyford target (top left), and "travelling laboratory" receiver (bottom left) used in the Daventry Test, 1934 (Ref. 172).

CHAIN HOME RECEIVE TOWER

---WITH ORTHOGONAL, HALF-WAVE DIPOLE ARRAYS AND SWITCHABLE REFLECTORS $\lambda/4$ BEHIND THE DIPOLES

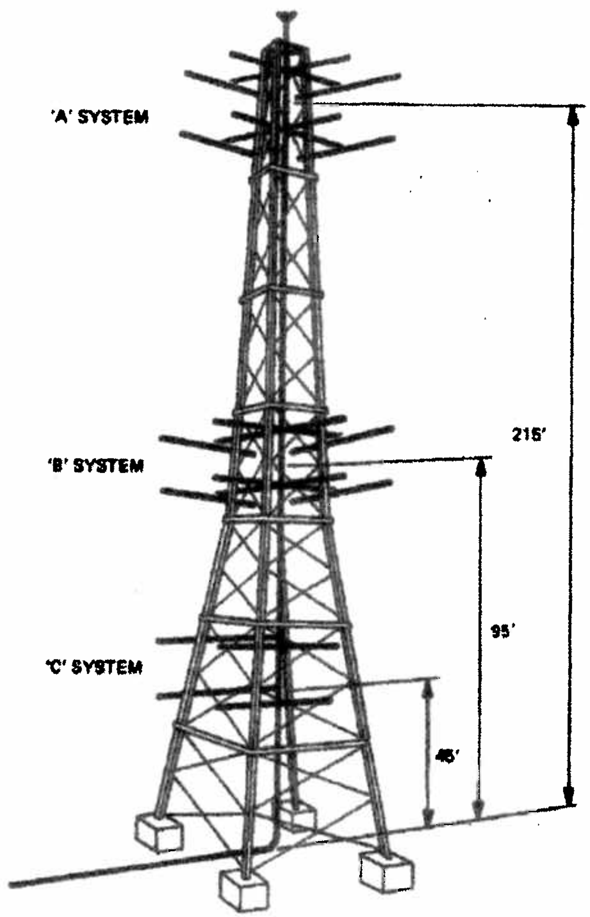
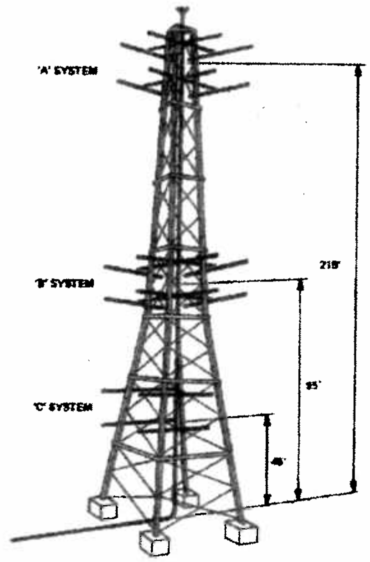
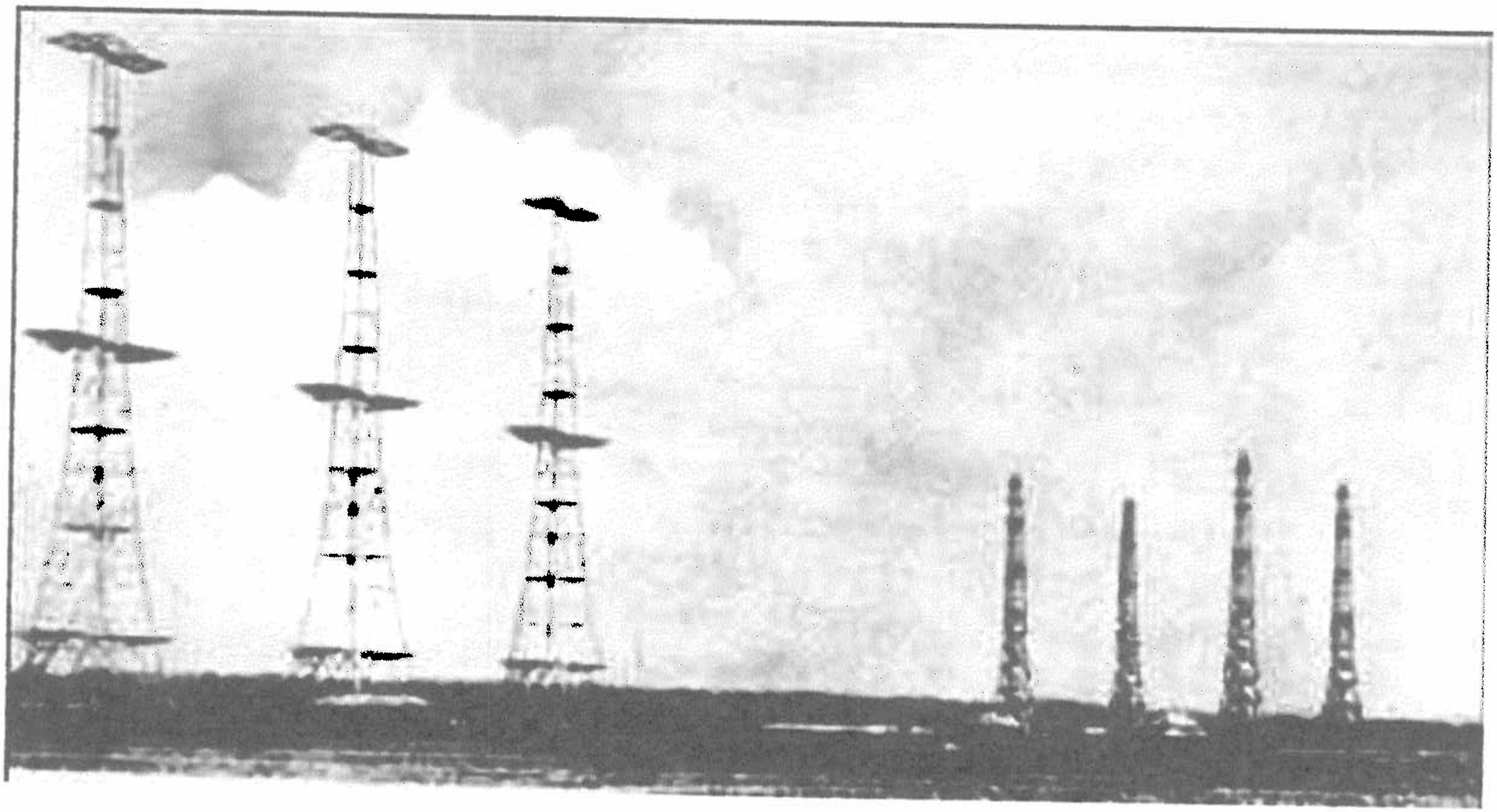


Figure 2.9. Orthogonal, half-wave, dipole arrays on a *Chain Home* receive tower [15]. The *A* system was the main array; an identical *B* system was used to fill the *A* system's multipath null and, with the *A* system, to estimate target height. The *C* system was used with the *B* system to measure height when the target was in the main array's null.
A *goniometer* compared signals from the two arrays to measure height and signals from the orthogonal dipoles in either array to measure azimuth. The measurements had a 180° ambiguity, which was resolved by placing remotely switchable reflectors λ/4 behind the dipoles, as shown in the figure, and noting whether the signal strength increased or decreased when they were switched in.



TYPICAL EAST COAST CHAIN HOME STATION



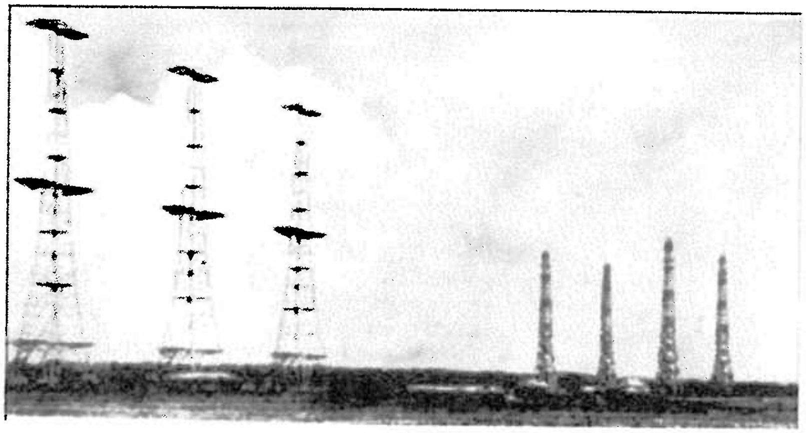
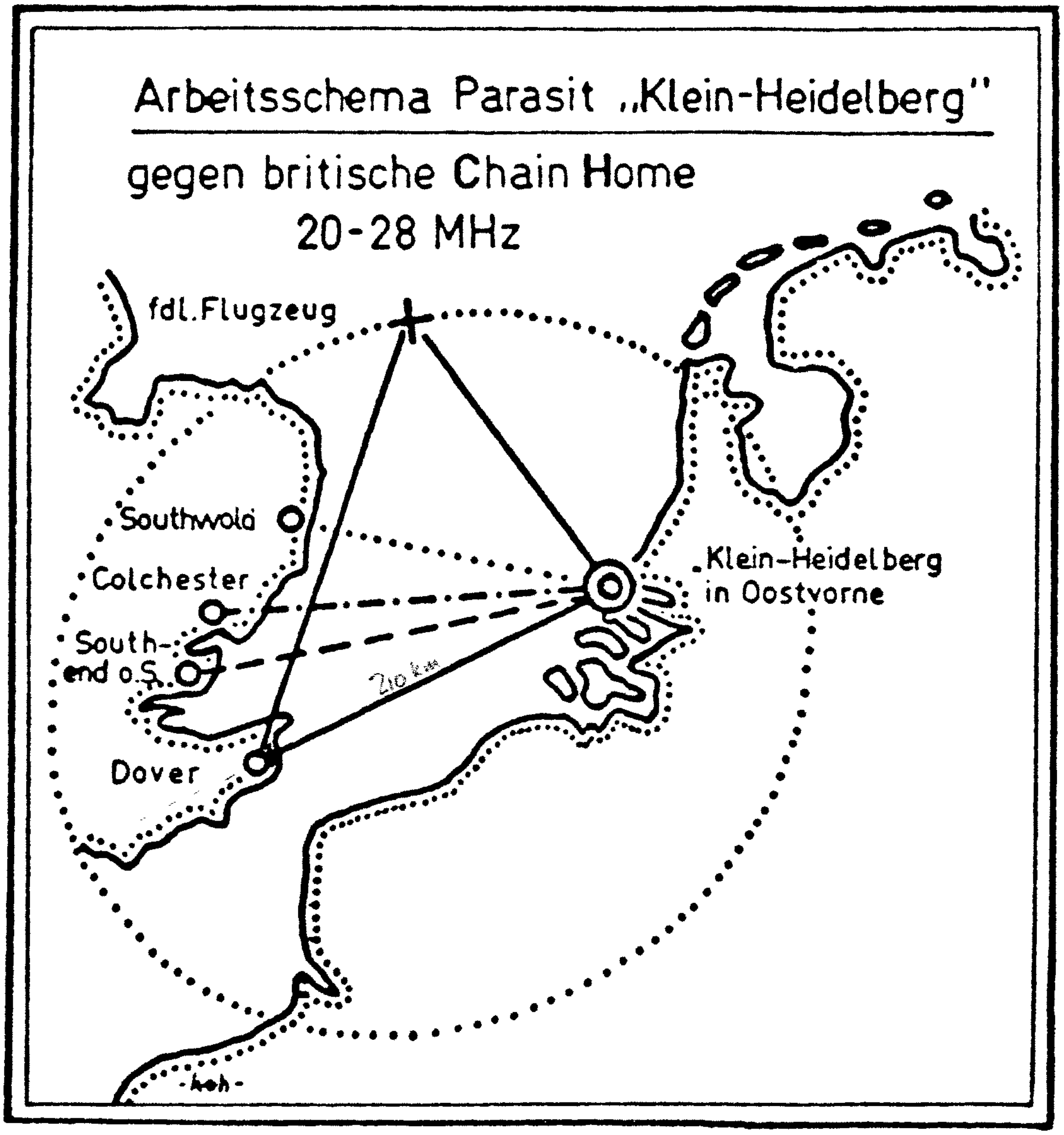


Figure 2.10. Typical East Coast *CH* station. The station employed three in-line, 109.7m steel transmitter towers spaced approximately 60 m apart. The transmitter *curtains* were slung between towers and fed by transmission lines leading from the heavily protected transmitter building nearby. Typical operating conditions were 20 to 30 MHz frequency, 350 kW (later 750 kW) peak power, 25 and 12.5 pulses/s PRF and 20 μs pulse length. Four 73.2 m wooden receiver towers, usually placed in rhombic formation are shown on the right. (See text and Figure 2.9 for their operation.) These towers and the associated receiver building were some hundreds of meters from the transmitter buildings and in some cases were in a separate compound. The dipole antennas on each receive tower were cut for a specific frequency, different from the others, as an anti-jamming measure. This plan was later abandoned. Important considerations for siting CH stations, circa 1936, included being well back from the coast and inconspicuous from the air, having a smooth slope between the site and the sea and soil suitable for supporting the steel masts, and finally, not gravely interfering with grouse shooting [15].

Spy's name : Lt. Kunkel



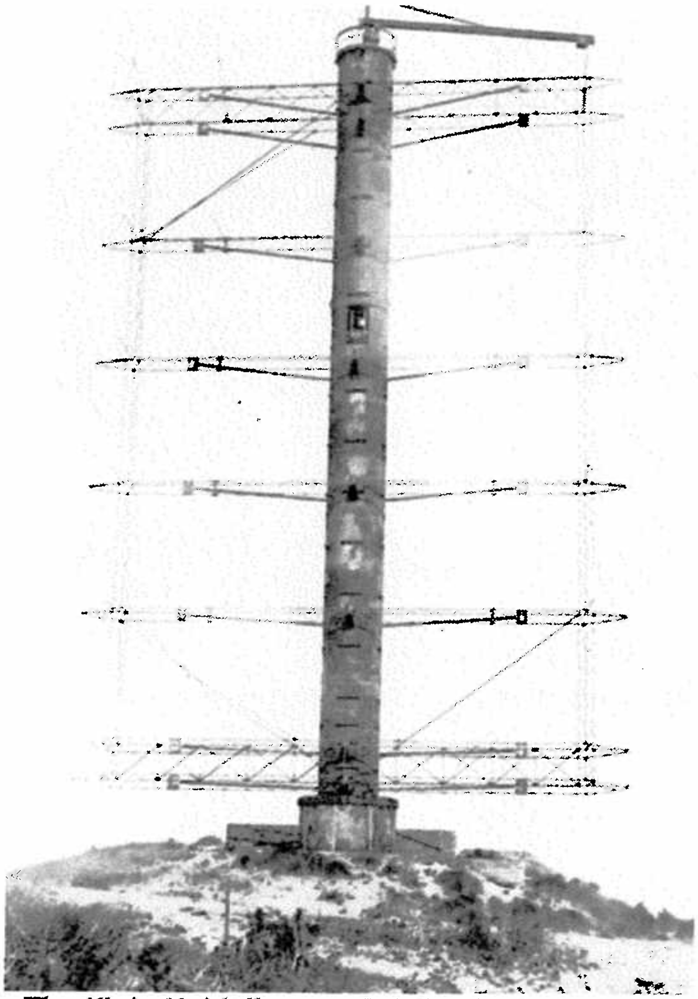
Zeichnung 15

Fig. 2 - Bistatic operation of a German «Kleine Heidelberg» receiver with a British «Chain Home» transmitter during World War II.

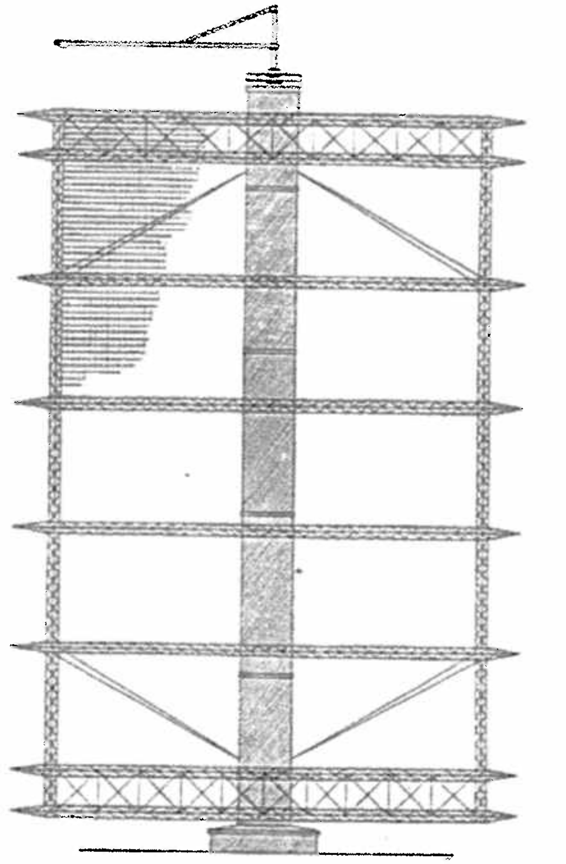
From: M.R.B. Dunsmore, "Bistatic Radars," Alta Frequenza, Vol. LVII - N.2, March-April 1989, p. 54.

Source: K.O. Hoffman, The History of Air Intelligence Unit, Book II, the World War, 1968, in German.

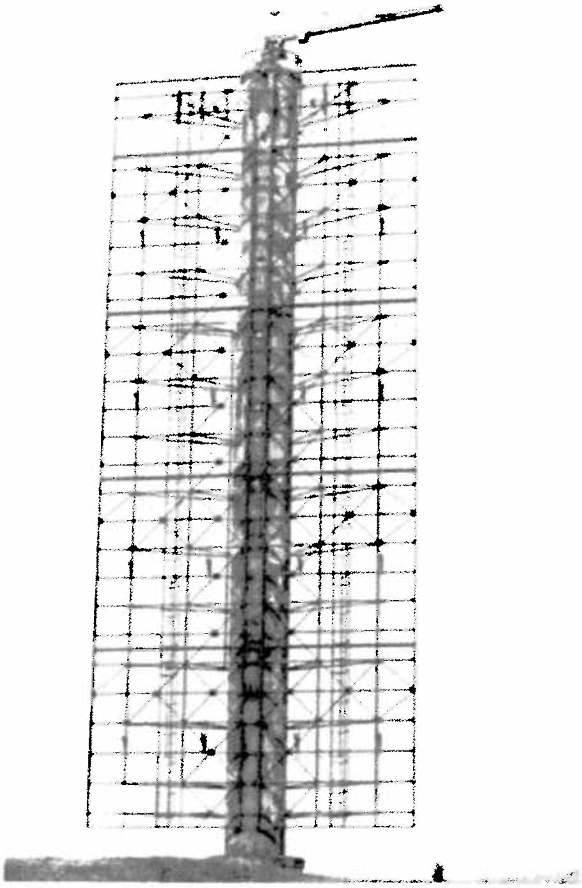
Assume ellipse is tangent to oval at extended BL (a max ? ..)
Then $R_R + R_T + L = 400$ km ; $R_T = 400 - 210$ km $= 190$ km
2.5 cm/100 km
$L = 210$ km, $e = \frac{210}{400}$ = .53
$R_T + R_R$ = 10.5 cm ≅ 400 km



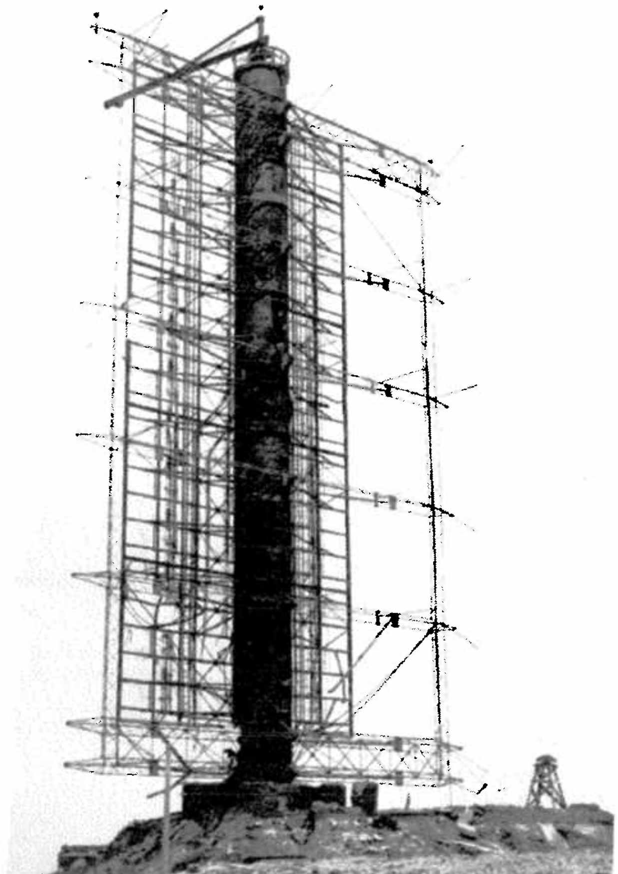
The Klein Heidelberg at BIBER, please note the absence of the Wassermann S antenna. © Jeroen Rijpsma, with his kind permission



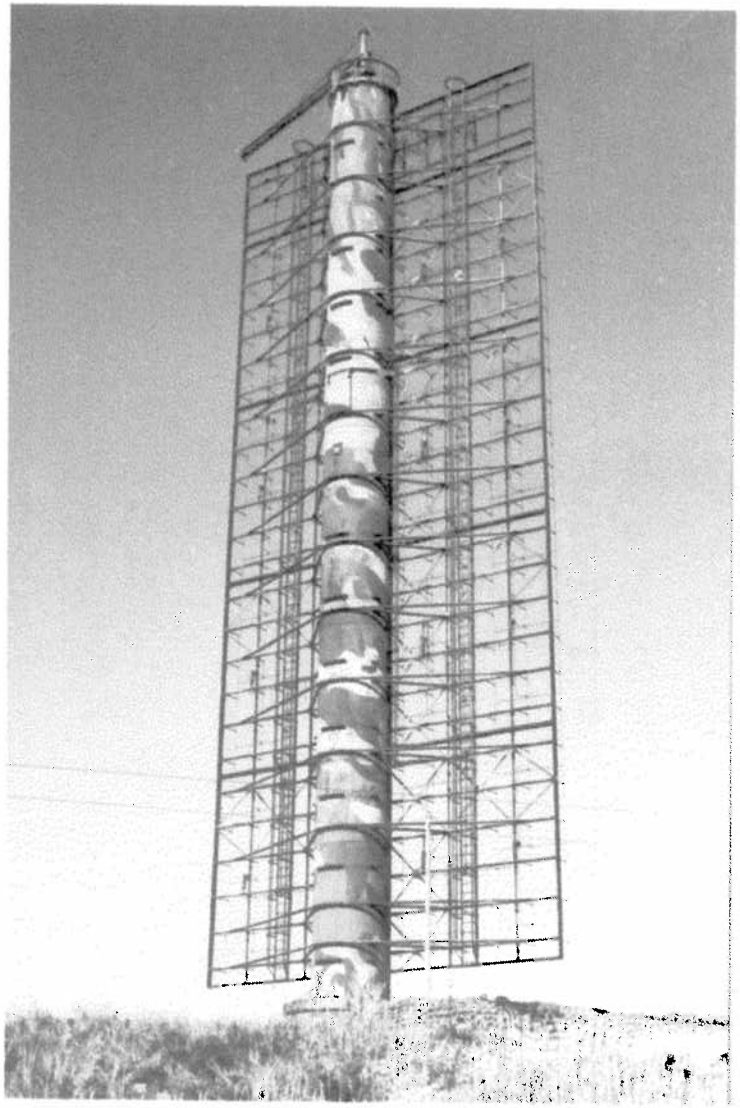
A post-war allied sketch.



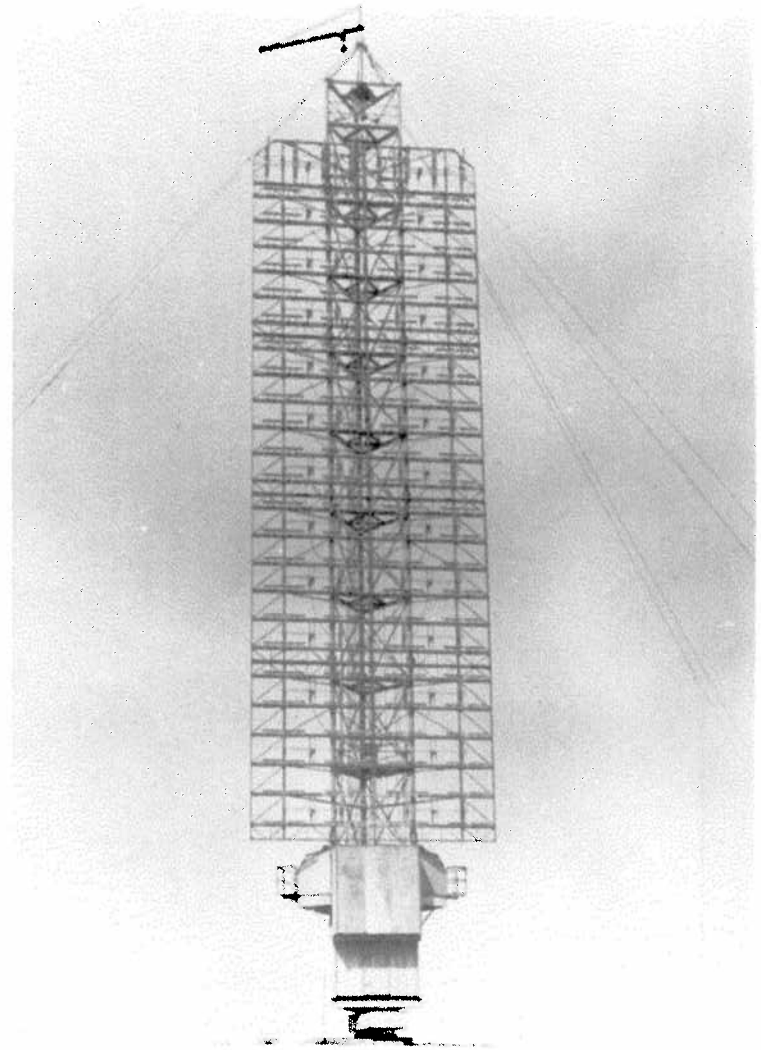
A "normal" Wassermann S at SCHAKAL (The Skaw).



A Klein Heidelberg in TAUSENDFUSSLER near Cherbourg. Please note the much wider and more "open" antenna. **In this site** the Wassermann S antenna was retained on the back-side.



Wassermann S.



Wassermann M II.

122-131 MHz
300km [illegible]

THE RUSSIAN ENTRY

---from V. S. Chernyak et al, "Radar in the Soviet Union and Russia: A Brief Historical Outline" IEEE AES Systems Magazine, 12 / 03

A. S. Popov was reported to have detected the *Lt. Il'in* as it crossed a comm link between the Russian ships *Europe* and *Africa* in 1897 on the Baltic Sea :

- Chernyak then credited Popov with discovering radio location
- Unfortunately nothing further was documented or accomplished
- So we shall *let it be*

amplitude (power), phase, polarization, reflection, refraction, diffraction and interference. He used reflectors at the transmitting and receiving positions to concentrate the waves into a beam.

Maxwell's ideas and equations were expanded, modified and made understandable after his death by the efforts of Hertz and the three "Maxwellians" George Francis FitzGerald (*1851-†1901), Oliver Lodge (*1851-†1940) and Oliver Heaviside (*1850-†1925) [5]. It is important to note that Hertz and the Maxwellians were not aware of each other's work until Hertz published his 1888 work. The Maxwellians appreciated Hertz's brilliant experiments and their implications and gave them the widest possible publicity and labeled them from the beginning as a decisive new confirmation of Maxwell's theory. The four equations in vector notation containing the four electromagnetic field vectors are now commonly known as Maxwell's equations. However, Einstein and Heaviside referred them as Maxwell-Hertz and Maxwell-Heaviside-Hertz equations, respectively. Since Hertz did not know anything about modulation of high frequency electromagnetic waves at low frequencies, he stated that waves with frequencies in the audio range (kHz) have too long wavelength and cannot be focused by reflectors so that they cannot be used for wireless telegraphy.

In 1887 Hertz also discovered the photo electric effect. He observed that the length of the spark between two electrodes increases when ultraviolet light falls on the negative electrode of a spark gap.

In the autumn of 1886 Hertz was offered chairs at the Universities of Gießen, Berlin and Bonn. His choice was Bonn where he became in April 1889 the successor of Rudolf Emanuel Clausius (*1822-†1888) and worked on "Principles of Mechanics" (1891). However, on January 1, 1894 he died at the age of only 37 years owing to a severe ear-, nose- and throat infection connected with a bone disease. H. von Helmholtz stated in his touching obituary: "He is a victim of the envy of the gods".

Fig. 8: Alexander Popov

The Russian Alexander Popov (*1859-†1906) (Fig. 8) demonstrated in 1895 his so-called "Thunderstorm Recorder" using aerial, coherer (invented in 1890 by Edouard Branly (*1844-†1940)) and electromagnetic relay. He succeeded in the transmission of the words "Heinrich Hertz" over a distance of 250 m. The antenna was mounted to a balloon. A few days later, also in 1895, Marconi transmitted and received a coded message over a distance of 1.75 miles and one year later he applied for the first patent in wireless, covering the use of transmitter and coherer connected to a high aerial and earth.

SO, DID ANY OF THESE PROFESSED "FATHERS" EVER CROSS PATHS?

INDEED THEY DID…

Figure 28
During a radar conference held in Paul's Church (Pauls Kirche) in Frankfurt in 1953, Hülsmeyer and Watson-Watt were both honoured guests. And, Watson-Watt had ultimately to admit that he was not the exclusive father of radar. We have recently found a photo (see previous page) on which Watson-Watt is looking in Hülsmeyer's folder, the modest smile on Hülsmeyer's face gives the impression that this could have been one of his finest hours![231]

W-W bypassed further discussion by stating; "I am the father of radar, whereas you are its grandfather."