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German WW2 ECM

(Electronic Countermeasures)

Adam Farson

VA7OJ

Glossary of terms

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- **Common acronyms:**
  - SIGINT: SIGnals INTelligence
  - COMINT: COMmunications INTelligence (communications between people or entities)
  - ELINT: ELectronics INTelligence (electronic signals not directly used in communications e.g. radar, radio-navigation)
  - ECM: Electronic CounterMeasures
  - ECCM: Electronic Counter-CounterMeasures
  - EW: Electronic Warfare (encompasses all the above)
- **System designators:**
  - AI: Airborne Interception radar
  - ASV: Air to Surface Vessel radar
  - CD: Coastal Defence radar
  - CH: Chain Home radar (CHL = Chain Home Low)
  - D/F: Direction Finding
  - Huff-Duff: High Frequency D/F
  - H_2S: British 3 GHz radar with PPI (plan-position indicator) display
    - (possible abbreviation for “Home Sweet Home”)
  - H_2X: US 10 GHz variant of H_2S

Scope of presentation

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- **Detection, interception & analysis**
  - Communications vs. radar monitoring
  - Direction-finding
  - Examples of COMINT, ELINT, SIGINT sites
- **Radar detection**
  - VHF/UHF & microwave radar detectors & threat receivers
  - Land, shipboard & airborne systems
  - Notes on German microwave technology
- **Jamming & spoofing:**
  - Radio communications: HF, VHF
  - Navaids: GEE, OBOE
  - Radar: VHF/UHF, 3 GHz, 10 GHz
  - Equipment examples
- **A case history: Operation Channel Dash *(Cerberus)***

COMINT/ELINT/SIGINT

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- **Communications monitoring**
  - HF and VHF land, sea and air radio interception
  - Decryption; content analysis, distribution to client agencies
  - Analysis of signals and equipment signatures
- **Radar monitoring**
  - Signal evaluation; pulse rate, spectral & signature analysis
  - Location of fixed radar sites
  - Identification of land, sea and airborne radars
- **COMINT/ELINT/SIGINT clients**
  - Countermeasures developers and operators
  - Tactical and strategic intelligence agencies
  - Field signals and radar formations
  - Naval and air force ECM units

Comms vs. radar monitoring

a question of bandwidth

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- Comms emissions & nominal bandwidths (in WW2)
  - A1A (CW), ≈ 150 Hz
  - A3E (AM) voice, 6 kHz
  - F3E (FM), 36 kHz
  - F1B (FSK) RTTY, 350 Hz
- Radar emissions & nominal bandwidths
  - CW/FM: 100 kHz – 1 MHz
  - Doppler: 100 kHz – 1 MHz
  - Pulsed: 1 – 10 MHz
- Receiver requirements differ radically:
  - Comms: freq. ranges 0.1 – 75, 100 – 156, 225 – 400 MHz (typ.)
    - CW, AM & FM detectors
  - VHF/UHF radar: 20 – 40, 100 – 400, 400 – 800 MHz (typ.)
    - CW, FM & pulse detectors
  - Microwave radar: 3 – 18 GHz; pulse detectors

Direction-finding (D/F)

an essential part of SIGINT

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- Interceptors needed to locate the source of the enemy signal as accurately as possible
- Omni-directional and highly directional antennas were used in combination to read bearing of signal
- Two or more sites could obtain position fix
- Same RX & antenna served for D/F and monitoring
- Comms D/F antennas:
  - HF: Adcock (4 verticals & goniometer)
  - HF: Rotatable loop
  - VHF: Yagi or corner reflector on rotatable mount
- Radar D/F antennas:
  - “Mattress” dipole array (rotary or fixed to ship superstructure)
  - Rotatable corner reflector (VHF/UHF)
  - Yagi array on aircraft nose
  - Microwave: horn, dielectric (polyrod), parabolic dish
    - Rotatable, or fixed to land vehicle

An early ELINT mission

- *and its failures*

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- On 2 August 1939, LZ130 *Graf Zeppelin* flew one of the first ELINT missions ever, off the British east coast with 25 RF engineers aboard. She was fitted with fairly broadband receivers covering 2 -100 MHz.
- Believing that Britain was developing radars in the same 100-150 MHz range as Germany, the team concentrated on that band. They never imagined that the British, limited by their tube technology, had developed a radar system (Chain Home, CH) working around 30 MHz.
- They picked up signals from the new 100 MHz R/T under development for the RAF, but strangely never followed this up!
- The German researchers picked up pulsed signals modulated by mains hum in the 20-50 MHz range, but discounted these as ionosonde signals or EMI from the UK national grid.
- In fact, as the British grid was synchronous, the 250 kW peak pulse CH transmitters were keyed from different points on the 50 Hz mains cycle to avoid co-channel interference between stations.
- This clever synchronization scheme totally misled the Germans!

Naval shipboard SIGINT/ELINT centre

Source: Fritz Trenkle

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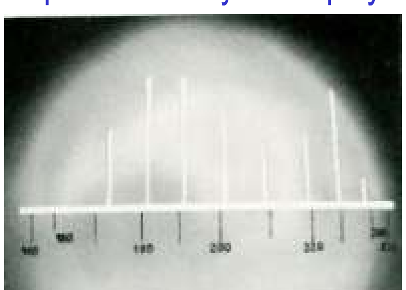
***Prinz Eugen* ECM centre in foretop.**

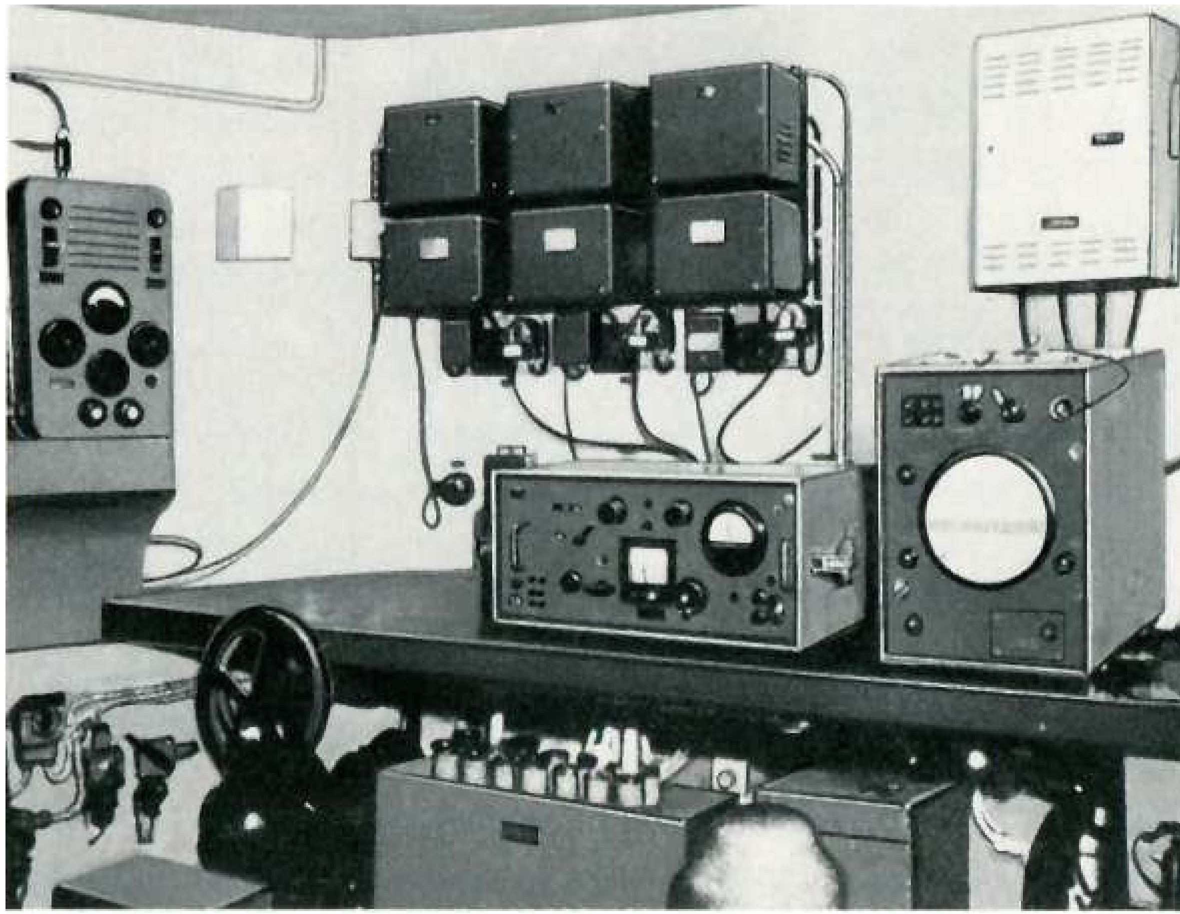
Table: R&S *SAMOS* receiver (80 – 480 MHz) & W.Anz g2 spectrum analyzer (146-254MHz).

Bulkhead above table: 3 *Naxos* radar detectors (3 GHz).

Source: Fritz Trenkle.

Spectrum analyzer display





Typical mobile COMINT station

Images courtesy LA6NCA

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Left: D/F antenna. Right: HF TX antenna.

Interior: Operator at EP2a RX (75 kHz - 3.3 MHz).

The interceptors passed their data to the ECM (jamming) unit via HF CW, with Enigma encryption. This was often most helpful to Allied ECCM if the traffic was decrypted in time.

Early radar detectors: *Metox, Naxos*

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- From 1940, RAF sub-hunter aircraft were fitted with 1.5m Mk. II ASV (Air to Surface Vessel) radar (180-210 MHz).
- Mk. II ASV could detect a U-boat at 20 km range. For night ops, a *Leigh light* (a powerful searchlight steered by the radar) was also fitted. The radar operator switched on the light when radar returns were lost, trapping the U-boat and allowing visual attack.
- *Metox* beeped on detecting radar pulses. The beep rate doubled when the radar operator switched to a higher PRF at closer range, alerting the U-boat to imminent attack. This allowed the boat to crash-dive in time.
- Rumours that the Allies were locating U-boats via *Metox* LO leakage proved untrue – but triggered orders to shut the system down fleet-wide!
- The advent of 3 GHz H_2S radar in 1943 neutralized *Metox*, so the German side developed the *Naxos* series. The US 10 GHz H_2X radar deployed by the RAF in 1945, rendered *Naxos* useless.
  - This is the nature of EW; measure, countermeasure, counter-countermeasure without end.

Examples of radar SIGINT:
FuMB 1 *Metox*

Source: Fritz Trenkle

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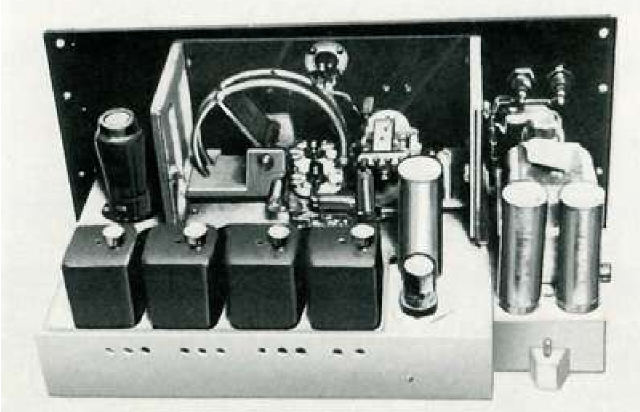
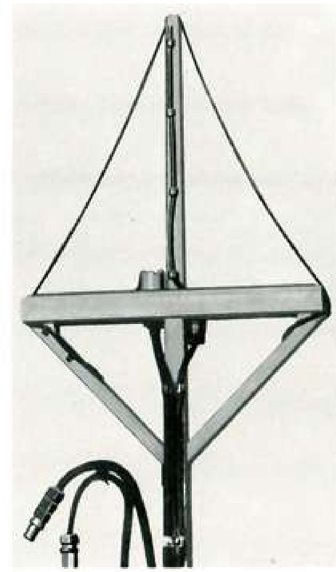
FuMB 1 *Metox*: fitted to U-boats to detect British ASV radar (180-210 MHz)

Receiver

RX interior





Erste FuMB-Anlage für U-Boote mit
Empfänger FuMB 1 „Metox" und
Antenne „Biskayakreuz"

***Biscay Cross* antenna: erected above conning-tower hatch & taken below prior to dive! *Bali* antenna replaced it.**

Newer U-boat mounted *Bali* circular dipole (90-470 MHz).

FuG 227 *Flensburg* detector:
countermeasure to RAF Monica
(FuG: Funkgerät = radio equipment)

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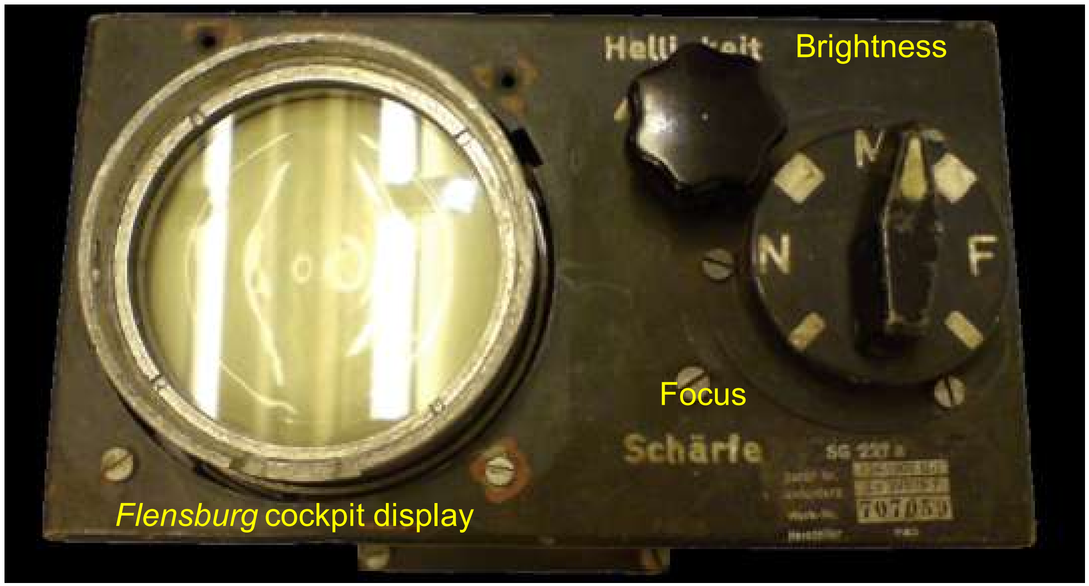

Flensburg **was a threat receiver fitted to Luftwaffe night-fighters in Spring 1944, and tuned to the 300 MHz emissions of the RAF *Monica* tail-warning radar. It had good sensitivity and angular discrimination, and enabled the fighter pilot to pick out a single bomber even in a stream, radiating multiple *Monica* signals.**

Flensburg **caused such an escalation in bomber losses that RAF Bomber Command ordered withdrawal of *Monica* from all its aircraft. Similar measures reduced the use of H_2S radar sets until the bombers were within 25 km of their targets.**

Examples of radar SIGINT:
FuMB 11 – 17 *Korfu* ground stations

(FuMB: Funkmeßbeobachtung = radar monitoring)

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FuMB 11 – 17 *Korfu* was a superhet system covering the microwave bands 1.6-7.5 GHz, later 7.5-11 and even 11.5-17.7 GHz. It was developed by Blaupunkt Radio GmbH. It gave bearings of aircraft operating H_2S/H_2X radar.

***Kornax-X*, with a rotating polyrod antenna, covered the 10 GHz band and was able to detect RAF and USAAF bombers assembling over the English coast, 550 km away. Another variant, *Naxburg*, used the Würzburg ground radar dish to increase gain.**

Korfu microwave radar threat receiver

Source: Arthur O. Bauer

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Plug-in tuning units cover 3 and 10 GHz bands.

Front end consists of semiconductor diodes (NF > 26 dB!) and a split-anode magnetron LO.

The *Naxos Z* Series:

U-boat, surface ship & airborne variants

Sources: Fritz Trenkle, Arthur O. Bauer

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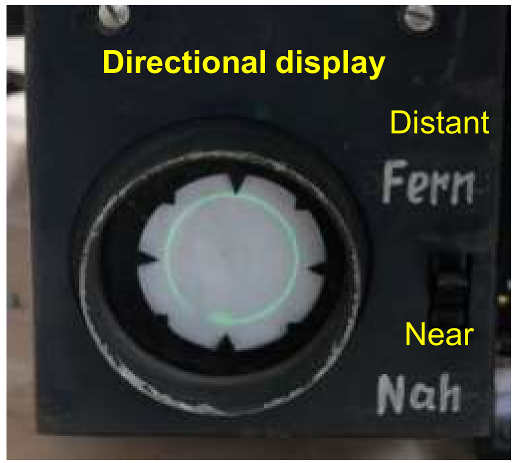
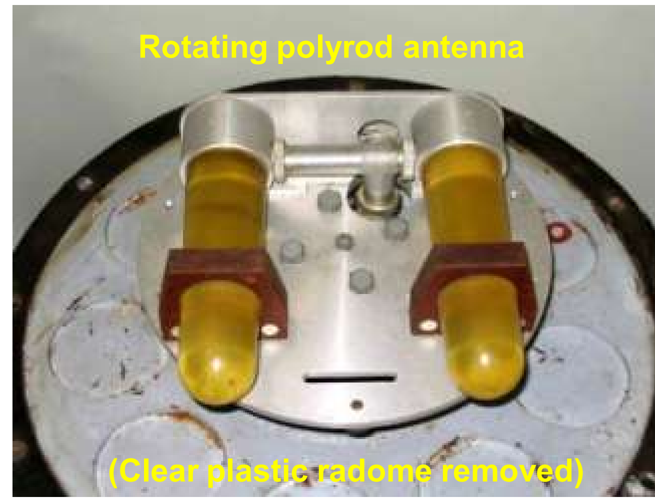
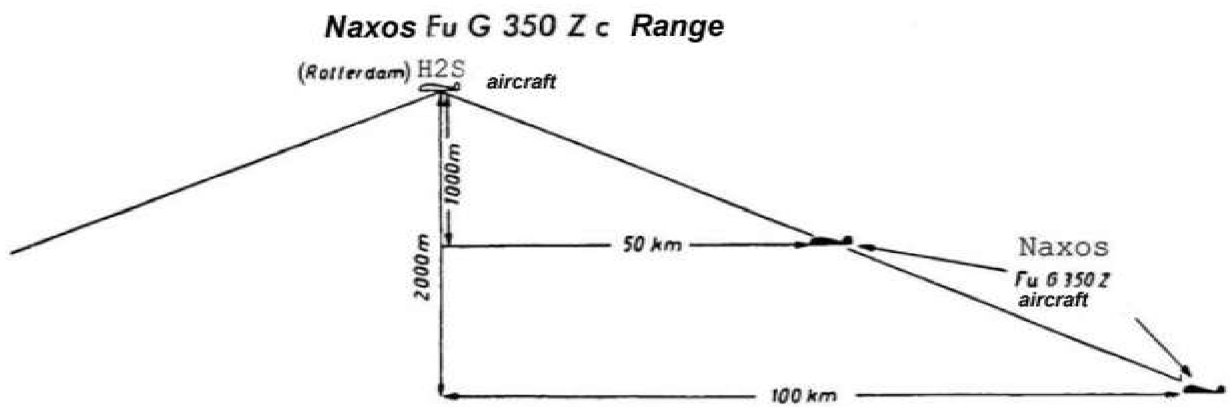
Sichtpeilanlage FuMB 23 „Naxos ZM 1"
(2500–3750 MHz)







The *Naxos Z* Series:

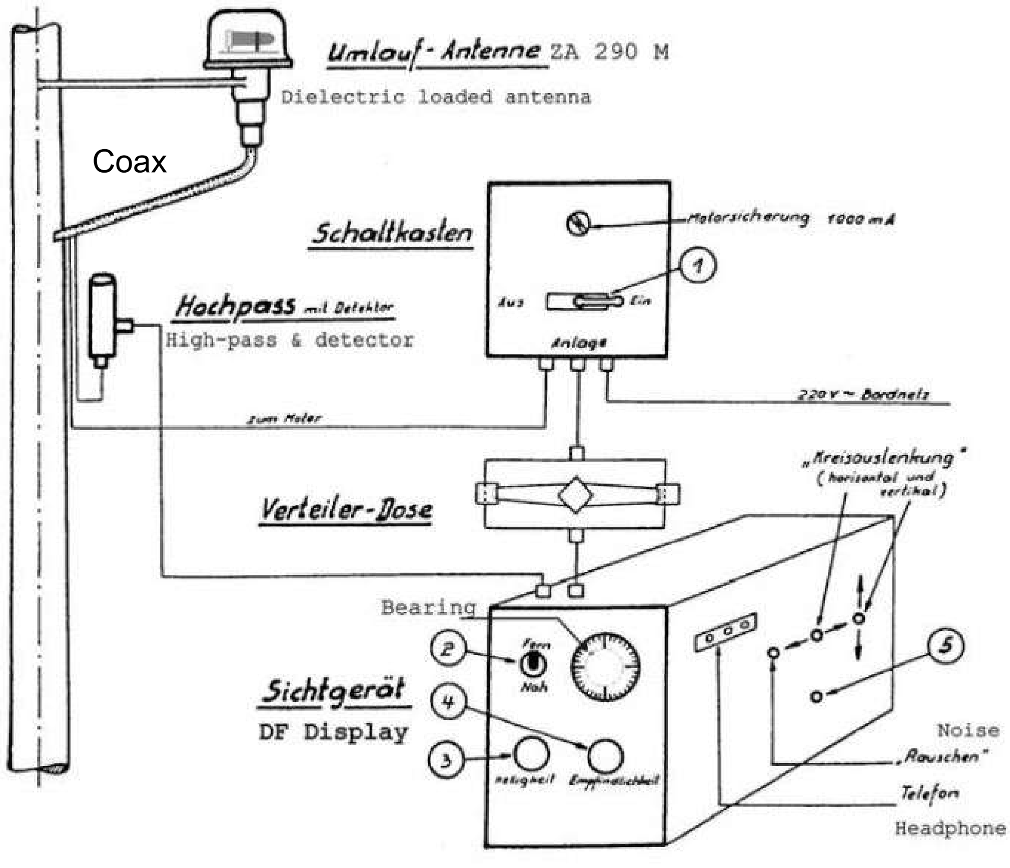
Block diagram

Source: Fritz Trenkle

Naxos was a wideband, untuned detector-type receiver – in effect, a crystal set. Initially, a ceramic HPF was fitted as shown, but this was later removed to improve sensitivity and reliability.

The polyrod antenna rotated at 1200 rpm to ensure capture of H_2S RF pulses. The detector output was modulated by the radar PRF and contained a 22 Hz component from the rotation.

The CRT was deflected circularly in sync with the antenna rotation, A 120 dB gain LF amplifier after the detector drove the CRT grid (Z-axis) to create a bright spot on the display when a signal was picked up.



Gesamtanlage Fu MB 28 (Naxos ZM 4) (System diagram)

No limit to the engineers' imagination - a body-worn detector!

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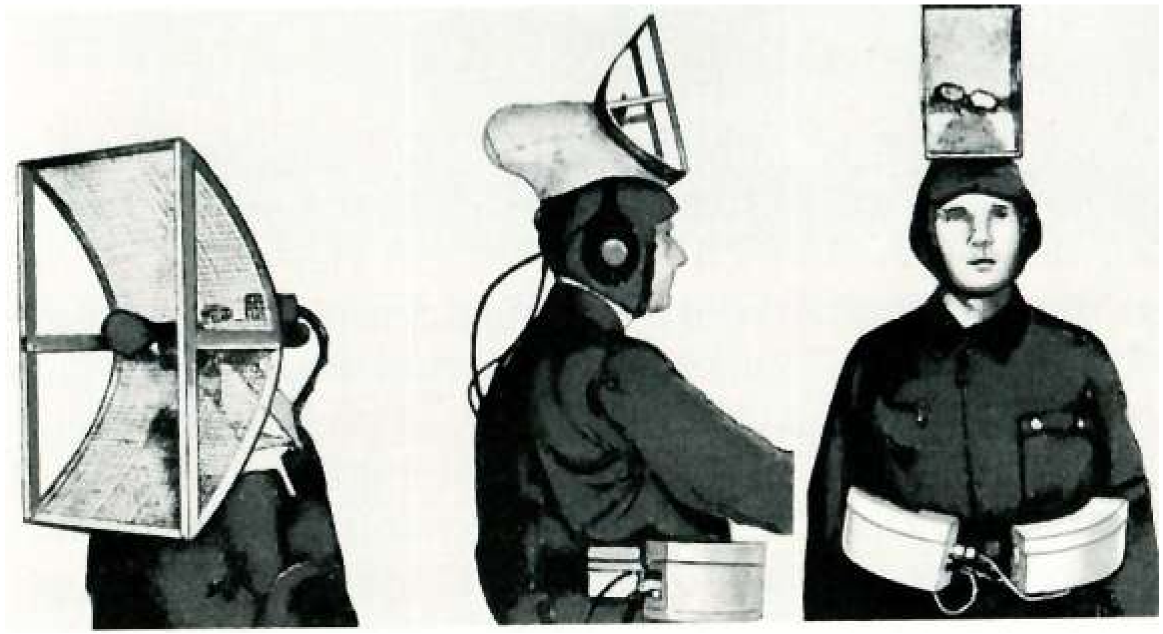

Telefunken FuMB 33 *Liliput 1* body-worn detector (2.5-3.75 GHz) for use in small craft without on-board power. The belt-worn amplifier was fragile and had poor sensitivity. Due to the 50° beamwidth, the operator "scanned" by constantly turning his head back and forth. Deployed in September 1944; 300 units built. Also issued to U-boats.

Indicator, amplifier & batteries

Notes on microwave radar technology

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- It has been reported* that Hitler personally ordered the cessation of all microwave research in 1941-42. Early in WW2, German scientists tried to get his permission to work on the development of microwave radar. When told this might take several years, Hitler refused. His policy required that scientific research produce usable applications for the military within 6 months' to a year's time. Telefunken even closed their microwave research laboratories!

- Still, German intelligence and scientific personnel were desperate to discover what the Allies were using. They combed downed Allied bombers for radar equipment, hoping to piece together a working radar set, or even a recoverable microwave radar system. Ultimately they succeeded in salvaging enough of an RAF H_2S 3 GHz set (including the cavity magnetron) from the wreckage of a Stirling bomber in Rotterdam to build a workable system *(Rotterdam-Gerät).*

- The development of the FuG 350 *Naxos* family of radar detectors was undoubtedly one of the spinoffs from the H2S capture. (The modern term is “threat warning receivers”). The ever-increasing numbers of Allied bombers using 3 and 10 GHz drove German researchers into a frenzied effort to develop microwave radar countermeasures.   ***Source: Fritz Trenkle, "Die deutschen Funkmeßverfahren bis 1945"**

Limitations of German WW2 microwave receiver technology

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- A standing *Führerverbot* blocked all semiconductor research until 1944. As a result, the best German solid-state mixer/detector diodes had NF > 26dB. For critical applications, thermionic diodes were used (NF ≈ 16dB).
- Frequency generation above 1 GHz was also a major problem due to vacuum-tube limitations. The split-anode magnetron was used as LO at 3 and 10 GHz, but was unstable and limited in power output.
- The Allies used reflex klystrons as radar LO's, but Germany acquired this technology only after WW2.
- An irrational fear of LO leakage and consequent detection by Allied SIGINT inhibited deployment of VHF/UHF and microwave superhet detectors. This was later proven to be largely unfounded.
- Microwave test equipment was all but non-existent right up to war's end. The best lab signal generator used a *buzzer* as a signal source!
- Constant Allied bombing of electronics R&D and manufacturing sites, plus ongoing sabotage at sites in occupied Europe, created extreme shortages of specialized components such as tubes, RF tuning assemblies etc. Inter-organizational secrecy also created enormous difficulties.

Jamming objectives:
comm/nav, radar & broadcasting

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- Communications
  - Tactical ground radio (HF, VHF)
  - Airborne R/T (VHF)
  - Naval CW and R/T (LF, HF)
- Navigational aids
  - GEE (British VHF hyperbolic navigation)
  - OBOE I & II (VHF & UHF blind-bombing aids)
- Radars
  - VHF ground radar (CH, CD, CHL)
  - VHF airborne (AI, ASV)
  - Microwave airborne (H_2S, H_2X)
  - Naval shore radars (VHF & microwave)
- Broadcasting
  - BBC services to Germany & occupied Europe
    - Responsibility of Post Office, not armed forces

Communications jammers

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- HF: In general, the German monitoring sites preferred to glean COMINT from strategic HF comms links than to jam them.
  - Example: German "cracking" of London-New York R/T link used by FDR and Churchill.
- By contrast, tactical situations e.g. transmission of critical orders, reports on German force dispositions, emergency calls from convoys under U-boat attack etc. called for *ad hoc* jamming.
  - FuG10 HF transmitters (S 10 K, 70W) were modified to jam Soviet HF airborne R/T, but were never deployed. Ancient spark transmitters were even "dusted off" in a few cases!
- Land and shipboard HF transmitters (typ. 200W – 1.5 kW) were tuned to the target frequency and either keyed rapidly and irregularly or noise-modulated. A *spectrum analyzer* served as a tuning aid in some systems.
  - Examples: holding the mic to the HV dynamotor PSU, mic in aircraft engine housing.
- Allied VHF air/ground R/T in 100-156 MHz band was attacked by *Caruso* (30W), later by *Karl I* (400W) & *Karl II* (2 kW) jammers (90-150 MHz), *Starnberg II* (98-156 MHz, 20W) and FuG40 *Nervtöter* (Gadfly, 25W) covering 90-140 MHz. Lower-powered units were probably airborne. US deployment of UHF (225-400 MHz) R/T largely eliminated this problem.
  - Modulation: Caruso: 150 Hz triangular wave. Karl: sawtooth.

Telefunken AS60 HF transmitter

- suitable for jamming service

Source: Arthur O. Bauer

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The AS60 may have been designed by the same group as the E52 Köln receiver.

Bandswitched VFO drive unit with optical projection freq. display allowed precise tuning onto target signal. Freq. stability $5 * 10^{-6}$ per °C.

The AS60 was intended as a fixed or shipboard HF comms transmitter, but its high power and stability made it very suitable for jamming missions.

Jamming of navigational aids
GEE

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- GEE was a hyperbolic navigation system in which a receiver aboard an aircraft or vessel measured the time delay between two pulsed radio signals to yield a "fix". Operational until 1970.
- The system operated in the 20-30, 40-50, 50-70 and 70-90 MHz bands. The on-board receiver had plug-in RF units for rapid QSY in the event of jamming.
- The Germans captured receivers from downed bombers, and devised effective jamming systems in which "spoof" ground stations in France or Holland transmitted fake pulses.
- Using D/F receivers and loops, Allied radio operators could often identify false signals.
- The *Breslau I* (22-28 MHz) and *Breslau II* (40-50 MHz) jammers were very effective against GEE. Each had 5 1 kW PA's (2 LS180 triodes in push-pull) and a complex pulse modulator synced to the British GEE pulses.
- AM at 20 kHz could also be applied to the RF pulses for further confusion.

Breslau II jamming transmitter

- against GEE & British low-band radars

Source: Fritz Trenkle

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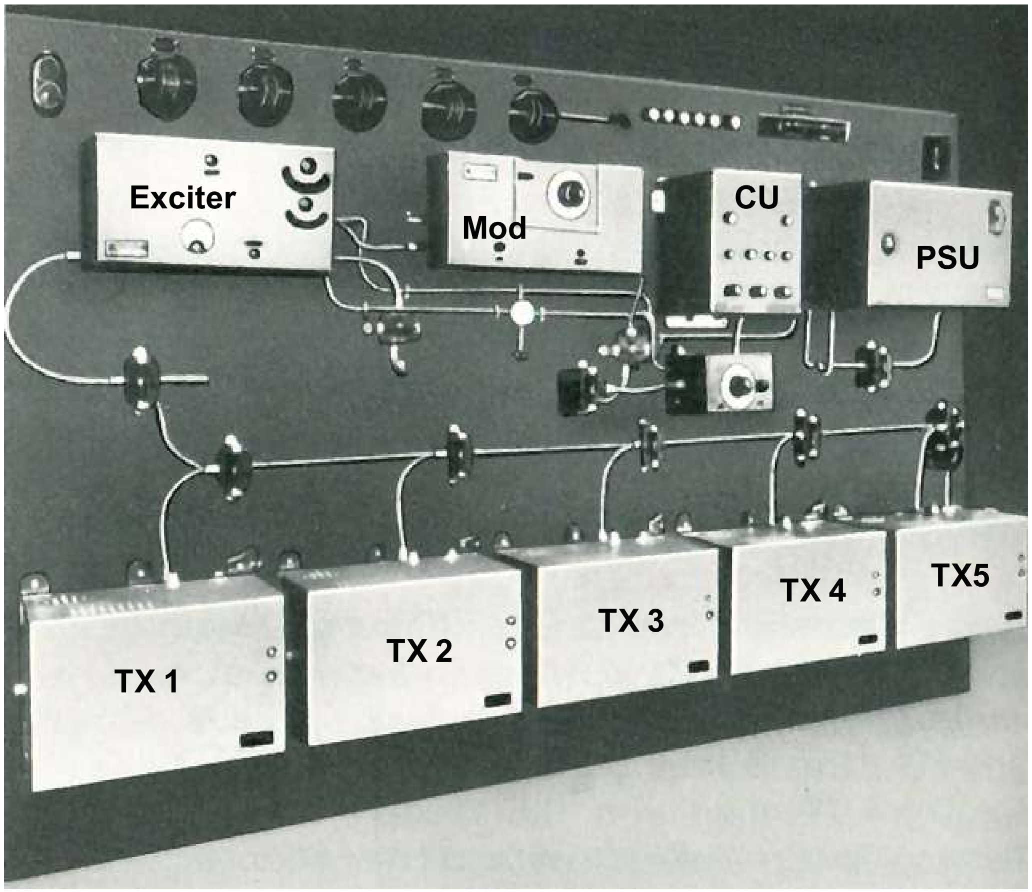

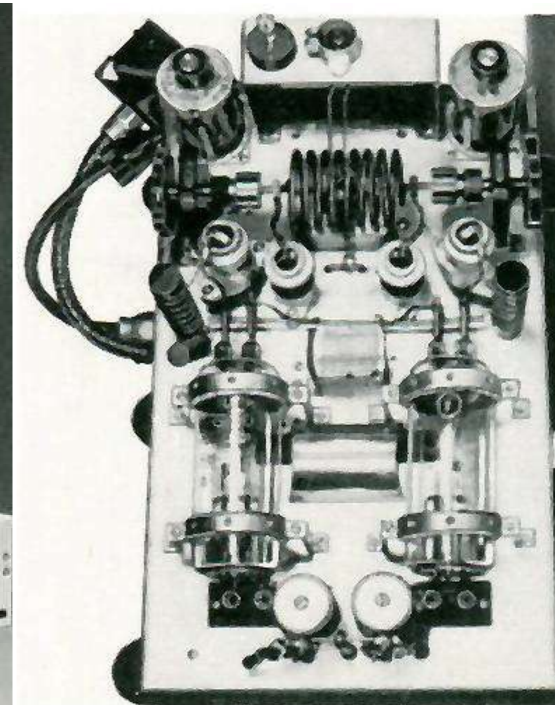

1 kW transmitter chassis
(2 X LS180 in push-pull)

Jamming of navigational aids
OBOE I & II (German codename Bumerang)

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- OBOE was a transponder-based aerial blind-bombing system using two fixed stations in England. These stations transmitted a signal to a Pathfinder bomber fitted with a transponder which repeated the signals to the ground stations.

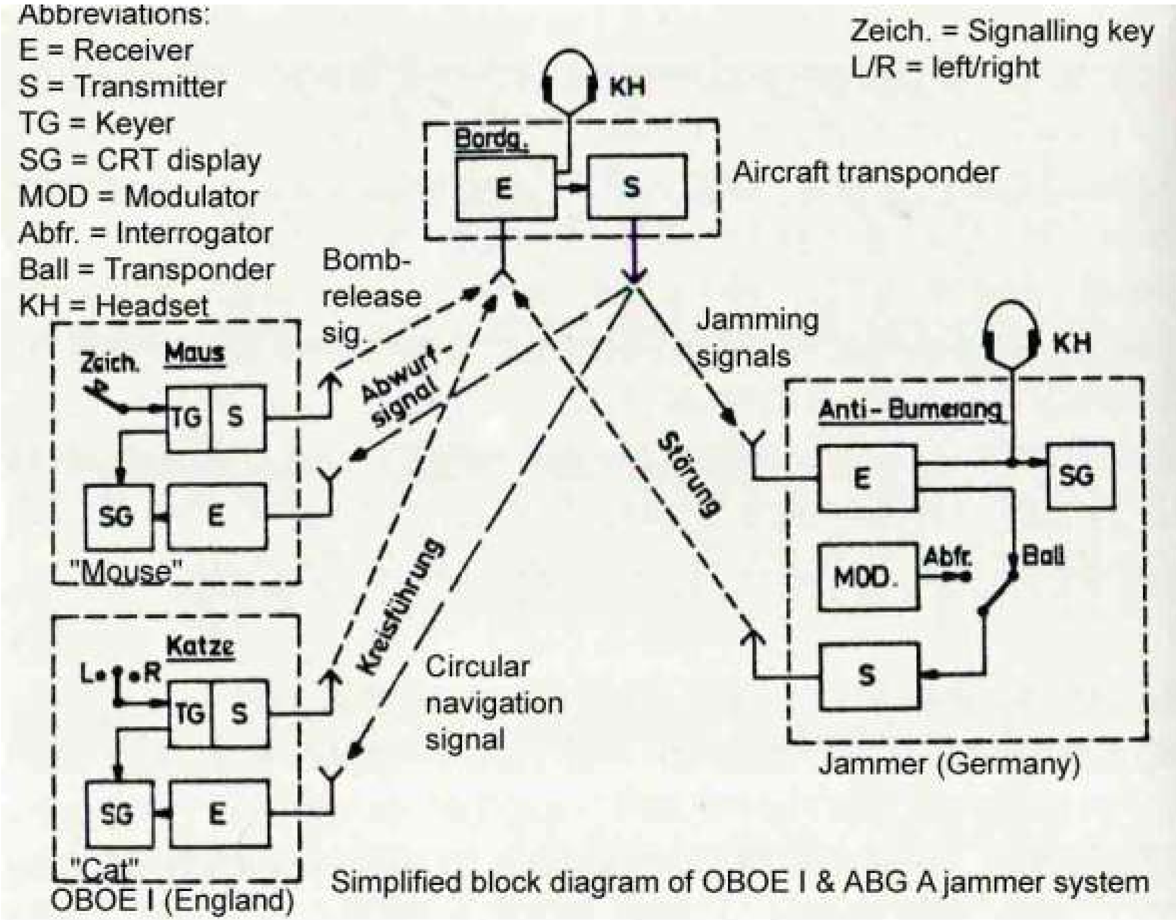
- The signal transit times enabled the ground stations to guide the bomber on a circular path to the target. A computer at one of the stations determined the bombs-away point, and transmitted the bomb-release signal to the bomber.

- OBOE 1 operated on 200-250 MHz with PRF ≈ 133 Hz. It was vulnerable to jamming and “spoofing” by ABG *(Anti-Bumerang-Gerät*), an interrogator-repeater system.

- ABG repeated the airborne transponder’s downlink signal back to the bomber on its uplink frequency at 25 kW peak pulse power and 200 Hz PRF, thus capturing the transponder in a feedback loop.

- OBOE II, operating at 3 GHz, evaded this jamming. Several Marks ot 3 GHz ABG were built, but never seriously compromised OBOE.

ABG *(Anti-Bumerang-Gerät)* A
- against OBOE I
Source: Fritz Trenkle



Simplified block diagram of OBOE I & ABG A jammer system


ABG A antenna mast

Jamming of British radars

VHF/UHF: CH, CHL, CD, AI, ASV

Microwave: H_2S, H_2X, newer AI & ASV

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- **Chain Home (CH) operated in the 20-55 MHz band; Chain Home Low (CHL) and CD (Coastal Defence) radar used the180-210 MHz band, as did Airborne Interception (AI to Mk V) and Air to Surface Vessel (ASV) radars.**

- **Prior to the cavity magnetron (early 1941), 200 MHz was the most widely-used band in Allied radar. *Düppel,* the German version of *Window* (chaff) used 75cm foil strips ($\lambda/2$ at 200 MHz). A variety of German jammers e.g. *Breslau II, Karl II* etc. covered 200 MHz.**

- **Microwave radar jamming was more problematical; the power levels required to jam effectively were beyond German capabilities. Transmitters using LMS 10 cavity magnetrons were unreliable and ineffective. *Postklystron*, a 100W transmitter using a water-cooled klystron with horn or dish antennas, was deployed in 1943-44 against 3 GHz radars (H_2S, newer AI & ASV) but had no strategic impact.**

- **By war's end, there was still no effective German 10 GHz jammer.**

General principles of radar jamming

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- "Brute-force" method, where an unmodulated or "wobbulated" carrier swamps echoes at radar receiver, is effective but requires very high ERP.
- Carrier modulated by triangular pulses with PRF slightly higher than that of target radar generates false echoes.
- Pulsed microwave jamming transmitter with pulse-shaping to enhance false echoes at target radar receiver, at PRF close to that of target radar, can "trash" PPI (plan-position indicator) displays.
- The pulsed microwave jammer can be even more effective if AFC derived from a receiver capturing the target radar's emissions holds the jammer exactly on the target's frequency.
- Despite some early successes, German radar jamming was strategically ineffective in the end as Allied technology was advancing too rapidly.

Karl I jamming transmitter(2 kW)
- against 200 MHz radars
Source: Fritz Trenkle

nsarc NORTH SHORE AMATEUR RADIO CLUB

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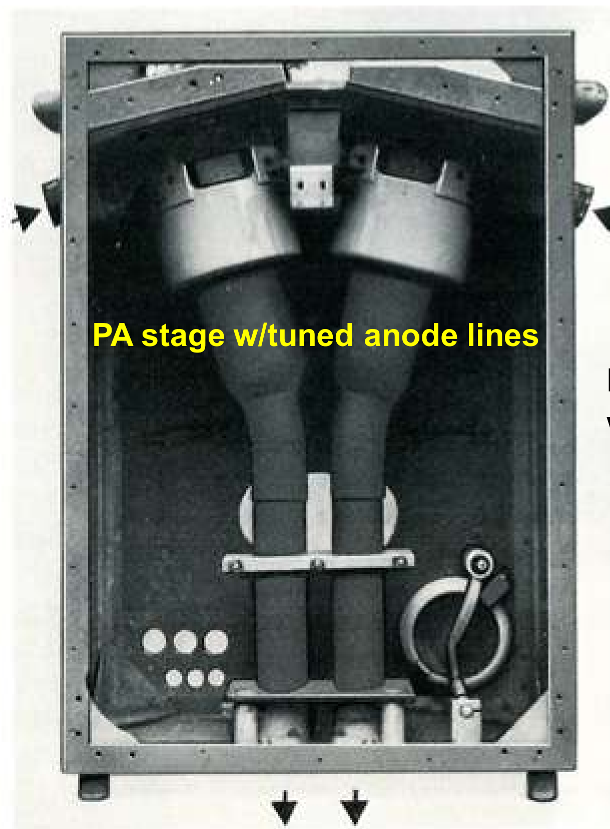

Modulation: Triangular waves at 150 kHz

Arrows: cooling air for grid circuit & output coupling loop

Examples of jammed radar displays

Source: Fritz Trenkle

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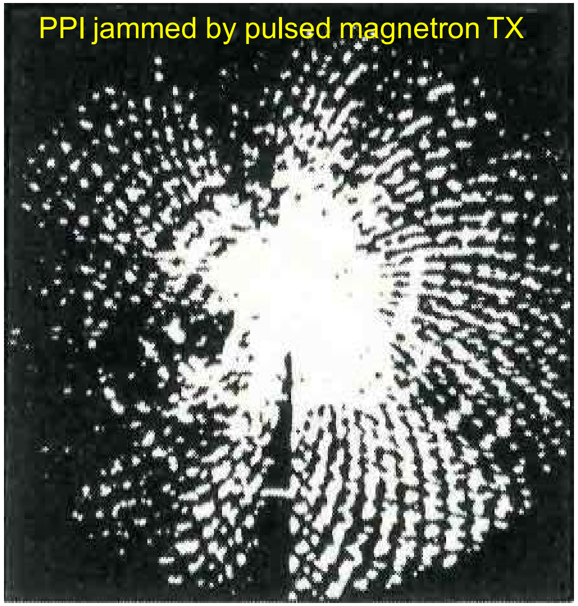
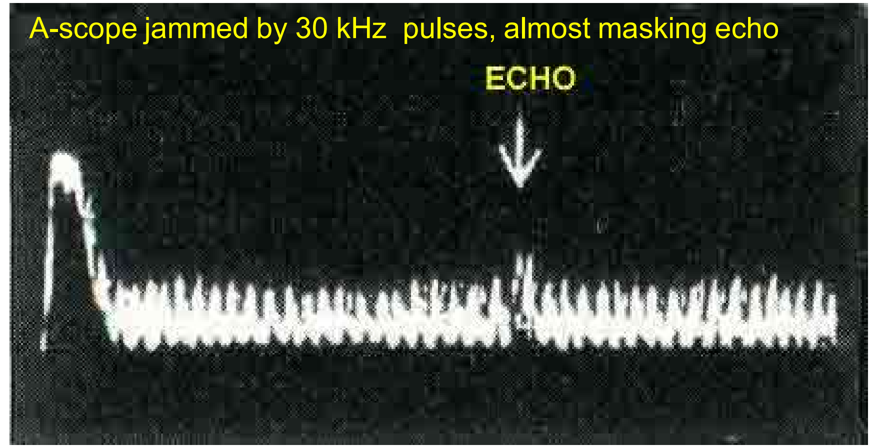
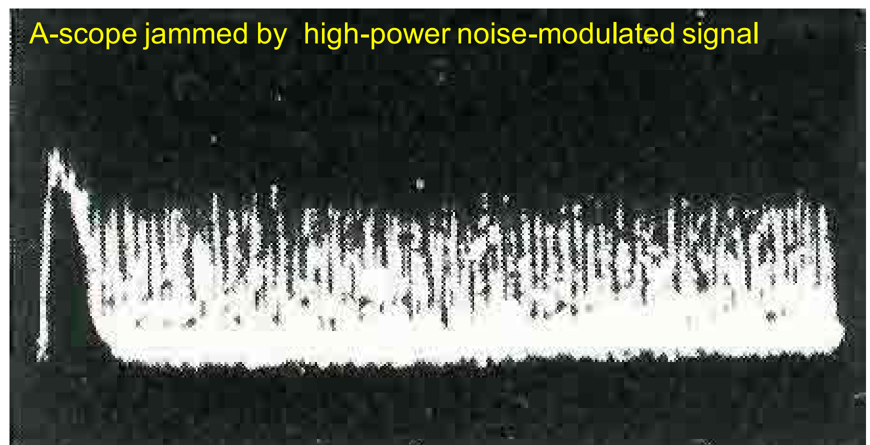


PPI jammed by pulsed magnetron TX



A-scope jammed by 30 kHz pulses, almost masking echo



A-scope jammed by high-power noise-modulated signal

Operation Channel Dash *(Cerberus)*
- a case history of radar jamming

nsarc
NORTH SHORE
AMATEUR RADIO CLUB

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- Operation *Channel Dash* (German: *Unternehmen Cerberus*) was the planned escape of the battleships *Scharnhorst, Gneisenau* and *Prinz Eugen* from the French port of Brest, up the English Channel to the North Sea and thence to Germany.

- A key component of the plan was the jamming of British CH and CD (CHL) coastal radars by multiple jamming sites along the Normandy coast. German accounts hold this up as key to the plan's success, but the Germans were unaware of co-sited 3 GHz CD Mk. IV (NT 271) radars which were thus not jammed. These radars detected and duly reported the escaping fleet.

- Ultimately, Channel Dash succeeded because of a number of snafu's on the British side; inter-service information barriers, RAF Coastal Command patrols with non-working ASV Mk. II (200 MHz) radar and radio silence rules blocking timely reporting of sightings. Inexplicably, the ASV's were not jammed.

- Despite their escape, all 3 battleships were effectively neutralized. Scharnhorst & Gneisenau were damaged beyond use, and Prinz Eugen was "stuck" in a Norwegian port until the end of WW2.

Acknowledgements & references

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1. Foundation for German Communications
2. Fritz Trenkle (many images)
3. Fritz Trenkle, *„Die deutschen Funkstörverfahren bis 1945“*, AEG-Telefunken
4. Alfred Price, “Instruments of Darkness”, Greenhill Books
5. Louis Brown, “A Radar History of World War II”, IoP Publishing
6. Werner Niehaus, *„Die Radarschlacht“*, Motorbuch-Verlag

Links for further study

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- http://www.radarworld.org/germany.html
- Foundation for German Communications
- Aspects of German Airborne Radar, 1942-45
- http://www.cdvandtext2.org/ADIK380all.pdf
- The Effects of Interception Procedures
  - **Interesting video on German ECM/EW, in German, notes in Dutch**

Future Presentations on German WW2 RF Topics

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- **Radio Direction Finding:** Allied & German land, airborne & naval D/F, including British "Huff-Duff"