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ELECTRONIC WARFARE
1914–2014

Radar & EW in the RAF

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Introduction

- **Electro-Magnetic Operations**:
  - Determine enemy use of Electromagnetic Spectrum
  - Degrade or prevent enemy use of Electromagnetic Spectrum
  - Maintain friendly ability to use Electromagnetic Spectrum
- Alphabet Soup:
  - EC, EW, IW, NAVWAR, Cyber
  - AI, AESA, RDF, Radar
  - ESM, RCM, ECM, ECCM, EPM, ELINT, COMINT, SIGINT
- ES, ED, EA are the new terms
  - **Electronic Surveillance**: Collecting information from the electromagnetic spectrum to understand the opponent's capabilities and actions:
  - **Electronic Defence**: Protecting friendly forces from threats that use the electromagnetic spectrum by providing warning of activity and taking action to degrade or prevent an attack
  - **Electronic Attack**: Deliberate actions to attack opponents through the electromagnetic spectrum in order to degrade or destroy their capability

- **Marconi** and **Ferranti** were involved from the beginning – both now **Selex ES**

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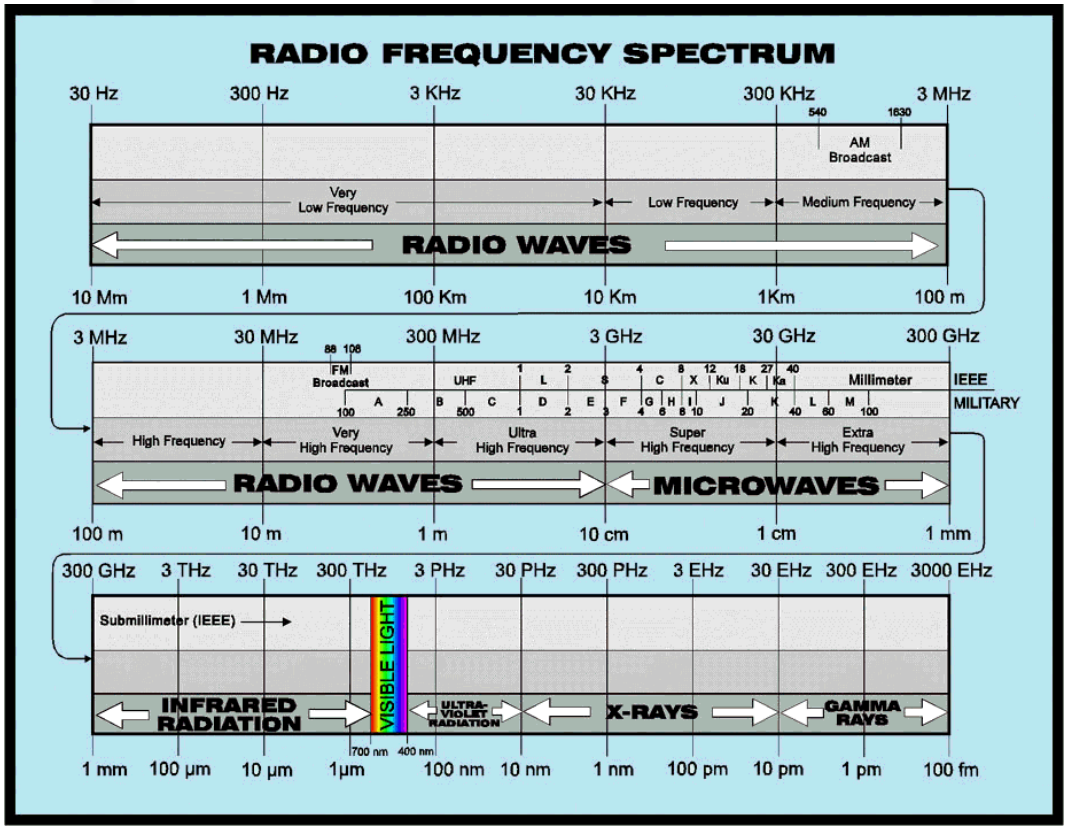
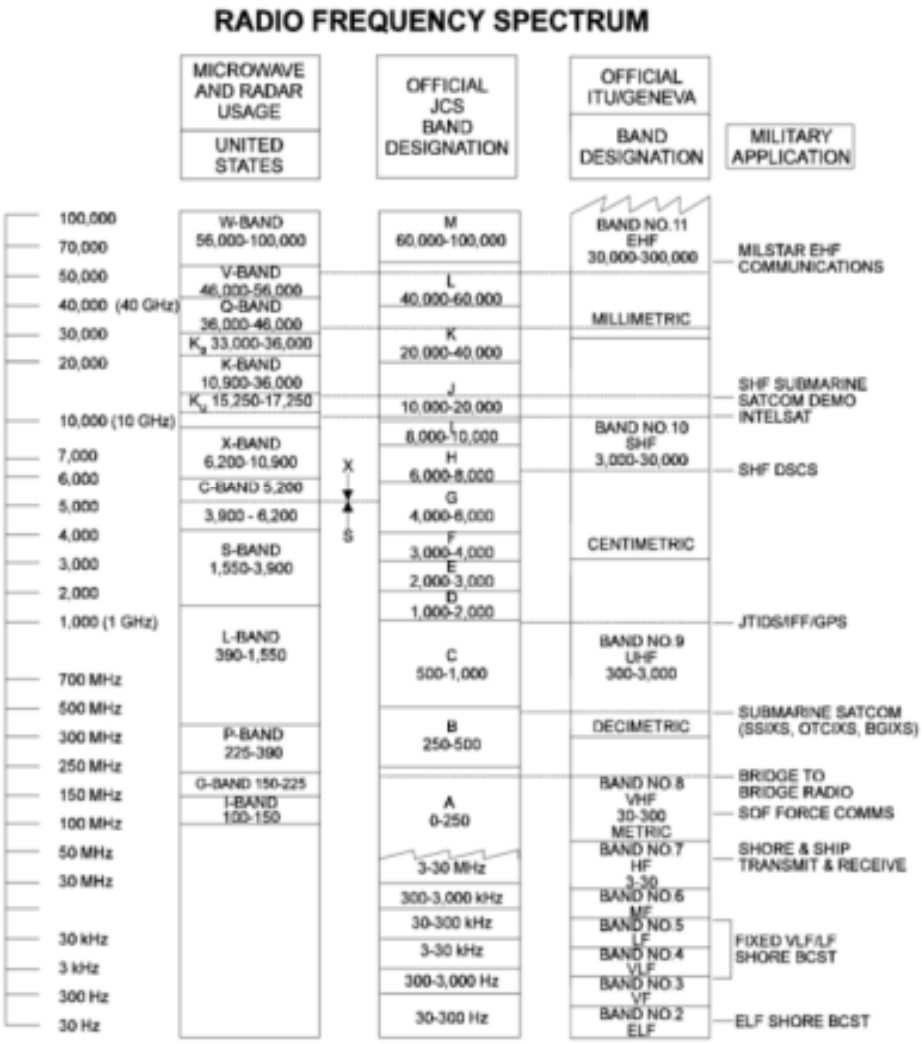
The Electromagnetic Spectrum





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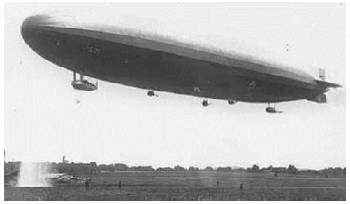
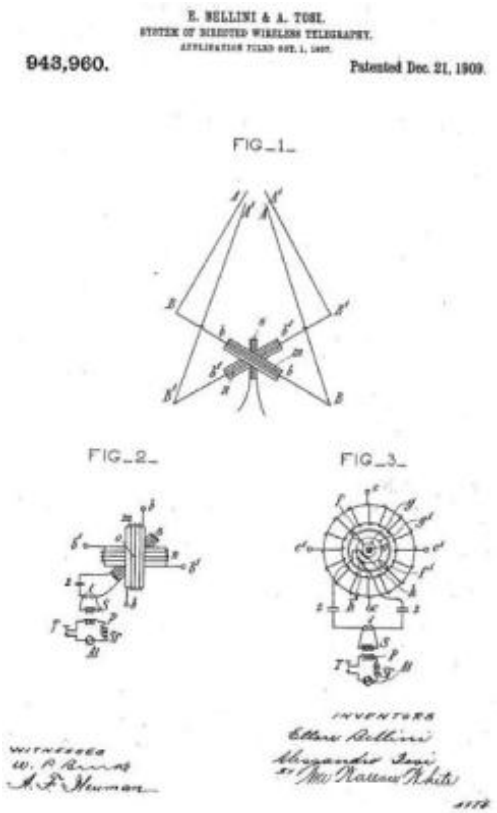


1914-18
"Y" Stations in World War 1

"Y" Stations in UK and France networked by telephone and telegraph to Whitehall

Marconi "C" Valve

Enabled high sensitivity receiver



Marconi Bellini-Tosi DF Receiver

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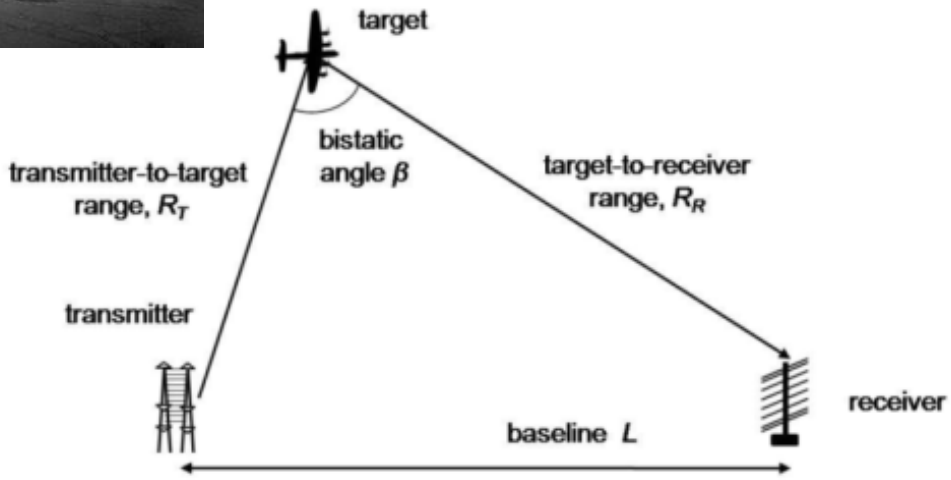
1935 – Watson Watt experiments

These experiments were of a bistatic radar configuration



Daventry – BBC Radio

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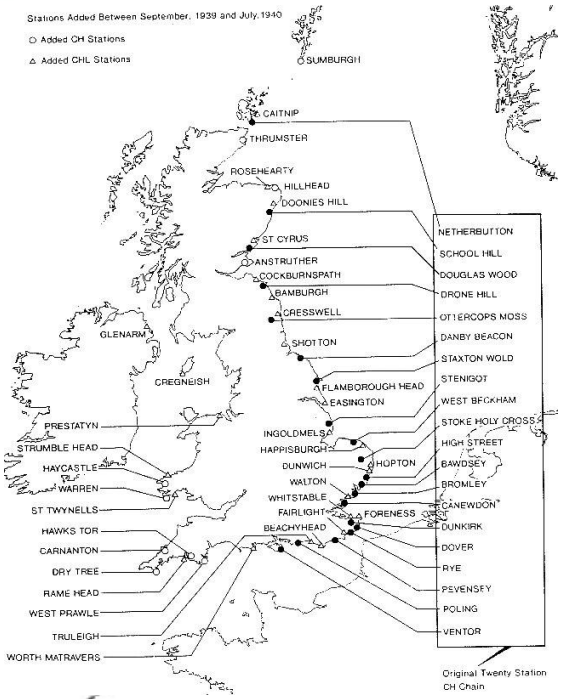
Chain Home

Chain Home
RF: 20-50MHz
PRF: 25Hz
PW: 20µs



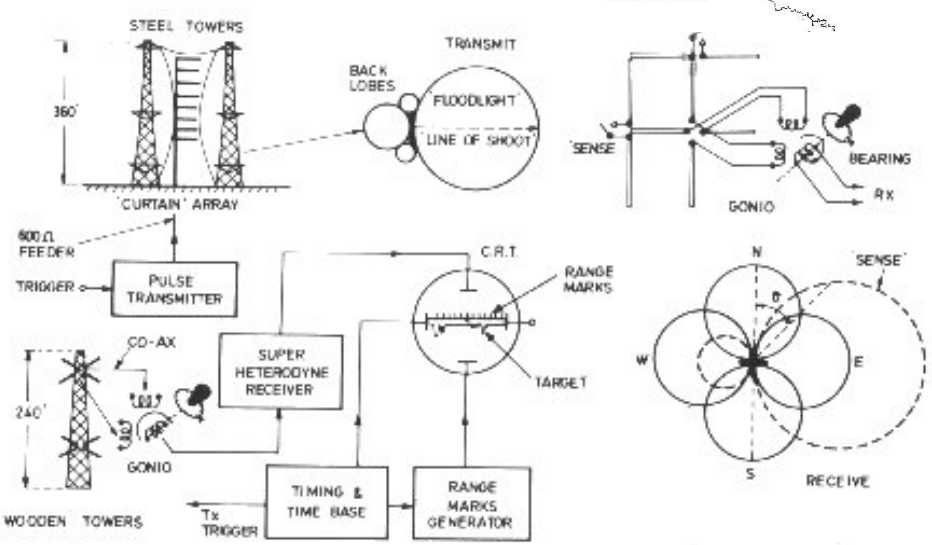


Fig. 1. Principles of CH (Chain Home) R.D.F. system

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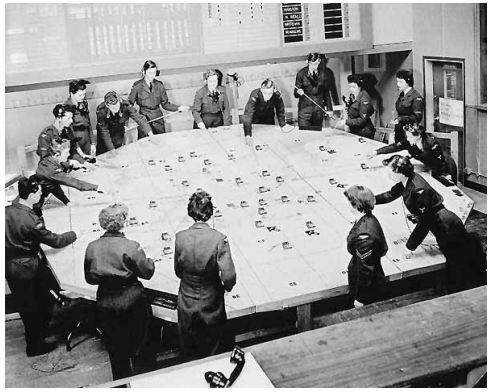
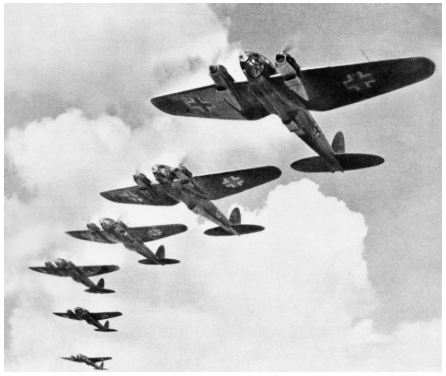
Battle of Britain (1940) and The Blitz (1940-41)





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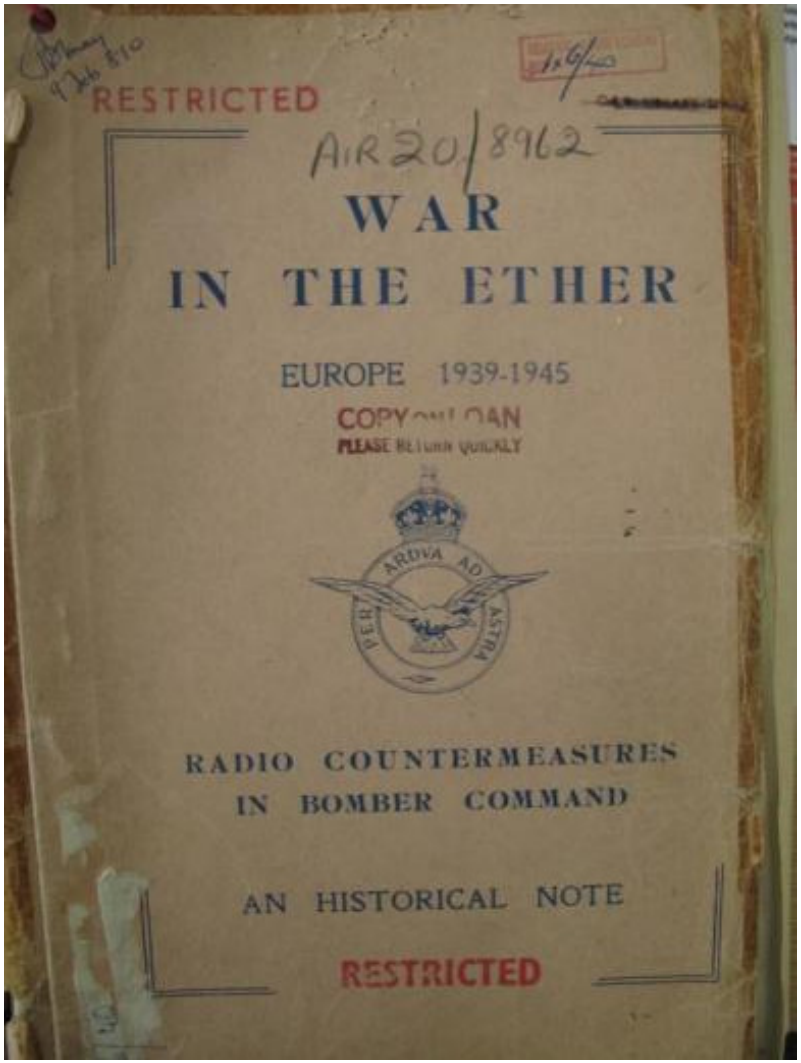
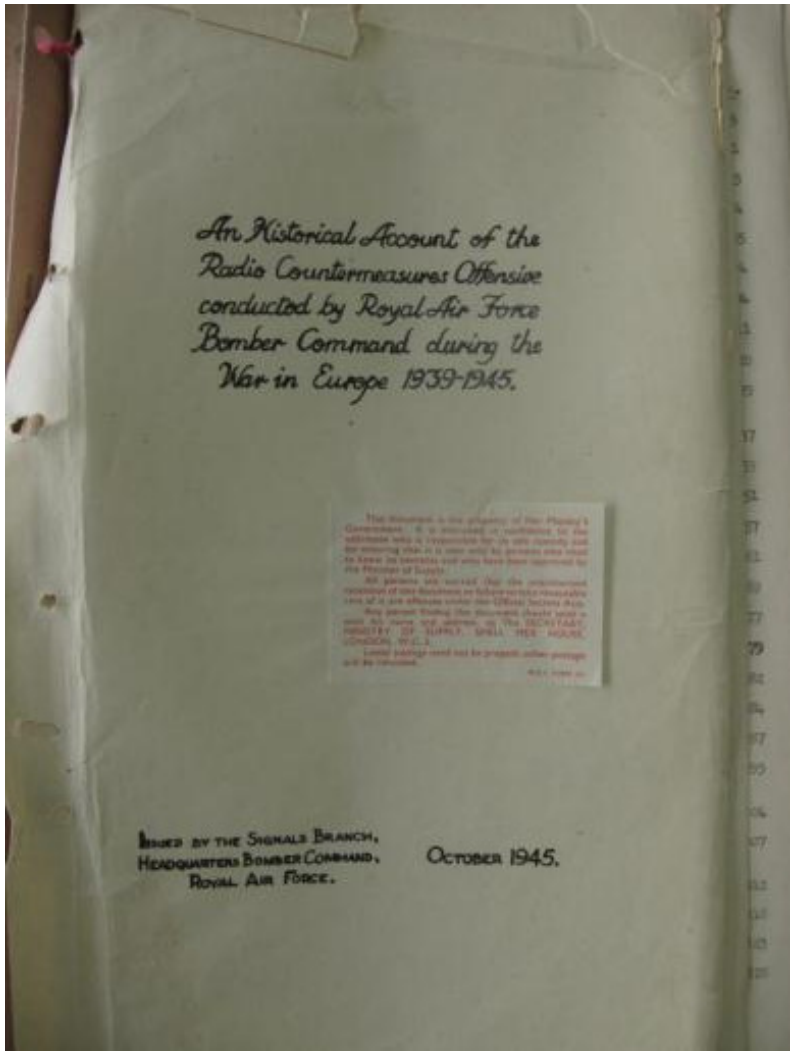
Radio Countermeasures 1939-45

Support to the British Bomber Offensive





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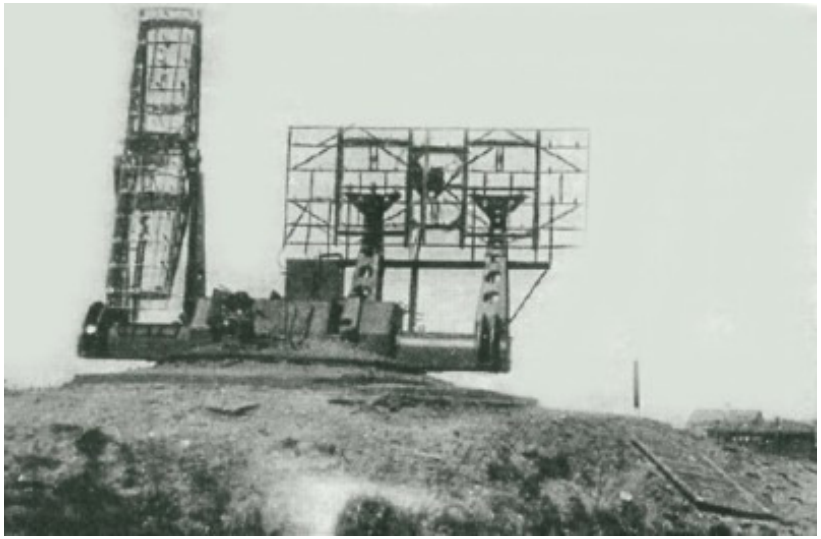
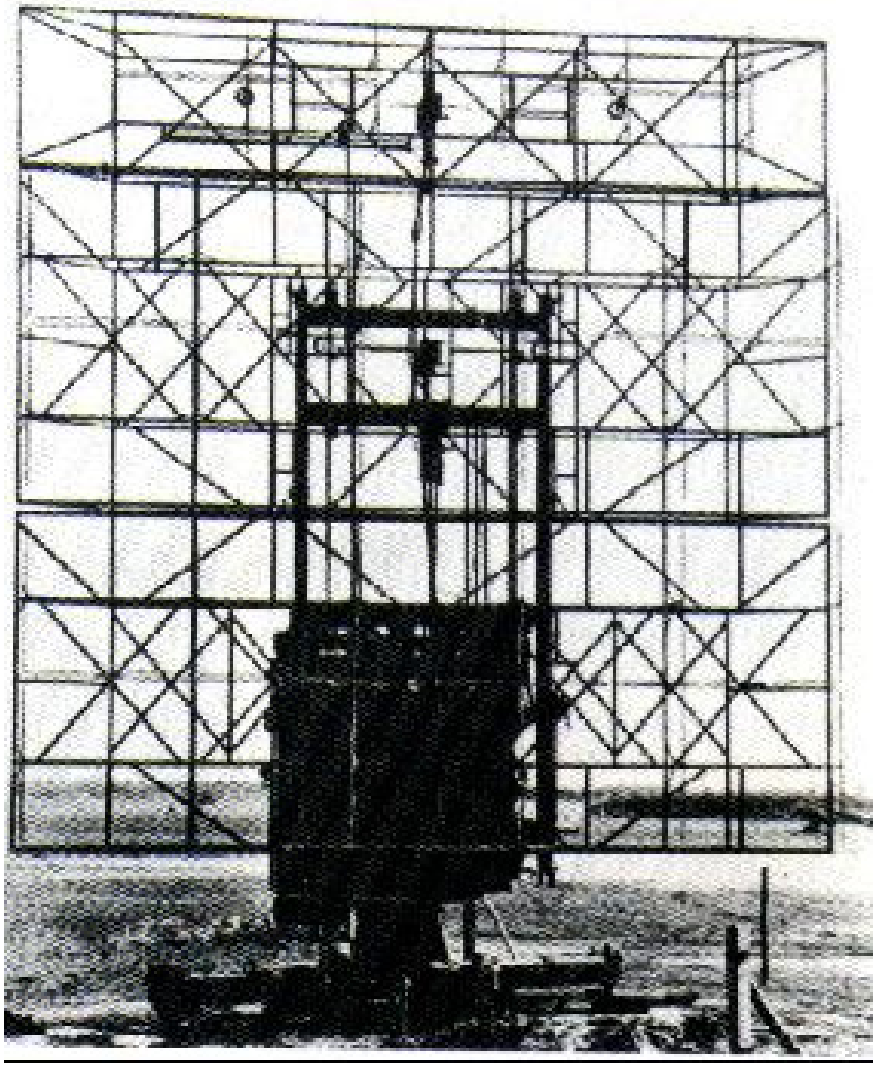
Freya - Surveillance Radar

Freya
RF 250 MHz (also 125MHz)
PRF 500 Hz
PW 2-3µs
Range 200km





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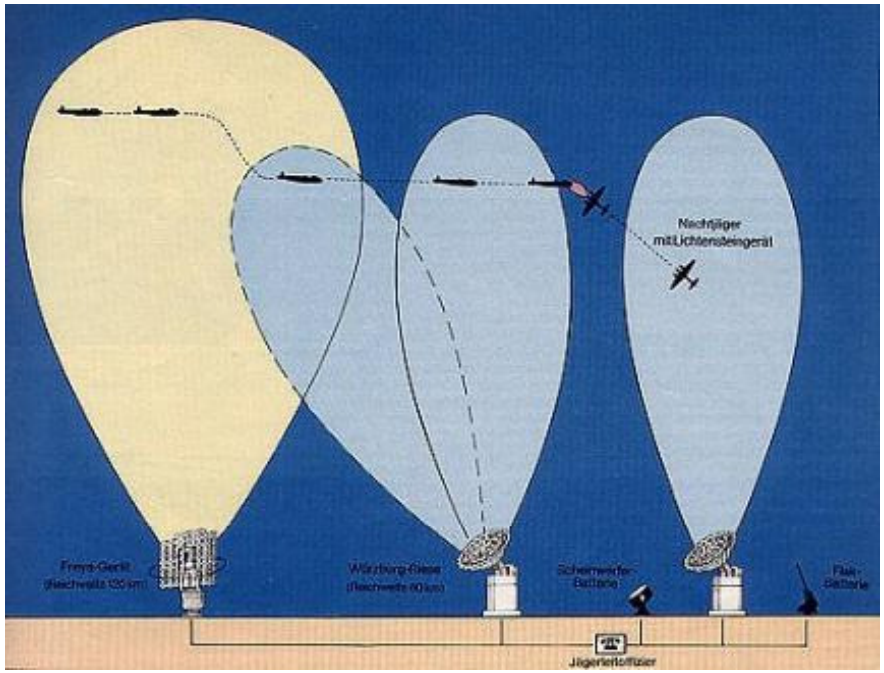
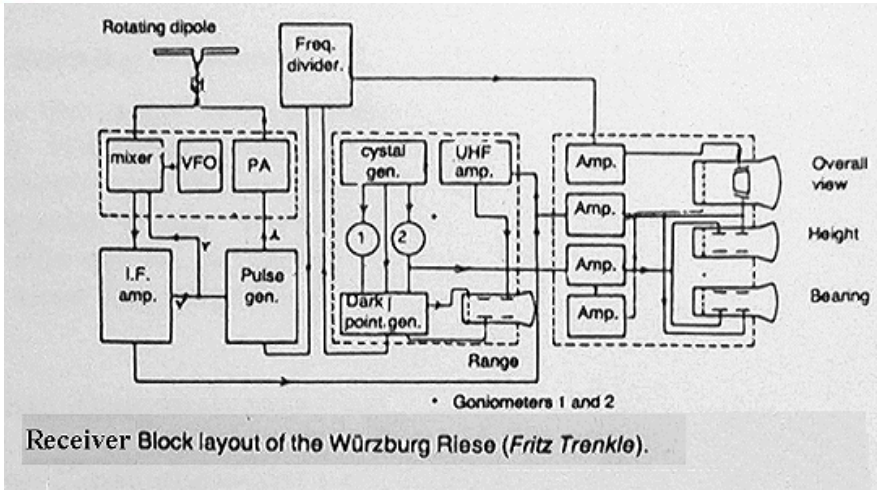
Wurzburg And Giant Wurzburg

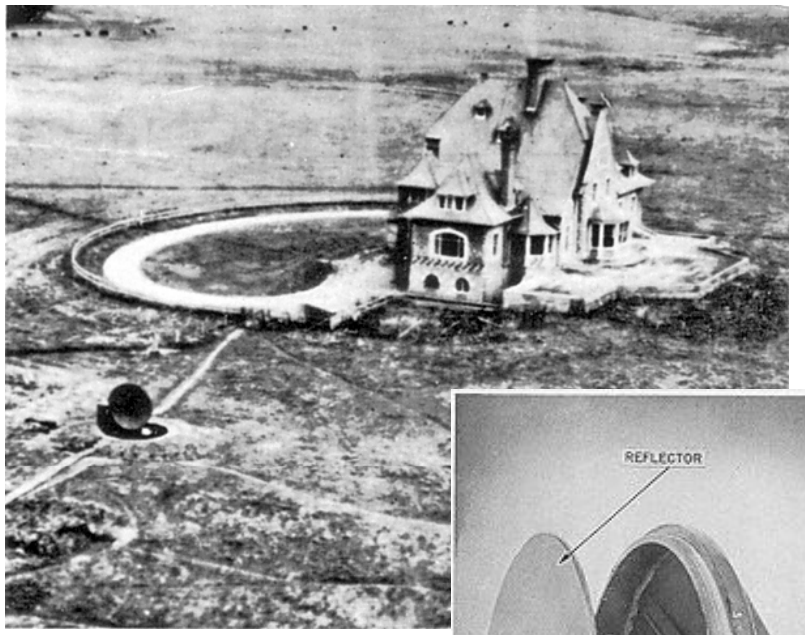


- Freya detected bombers
- One Wurzburg tracked a bomber
- One Wurzburg tracked and controlled a night fighter
- “Datalink” on ground
- VHF radio link to air

Wurzburg Radar
SIGINT and the Bruneval Raid



Receiver Block layout of the Würzburg Riese (*Fritz Trenkle*).



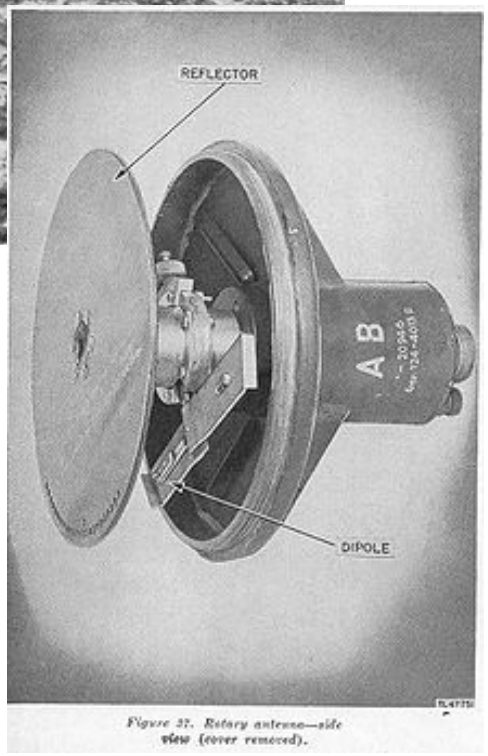
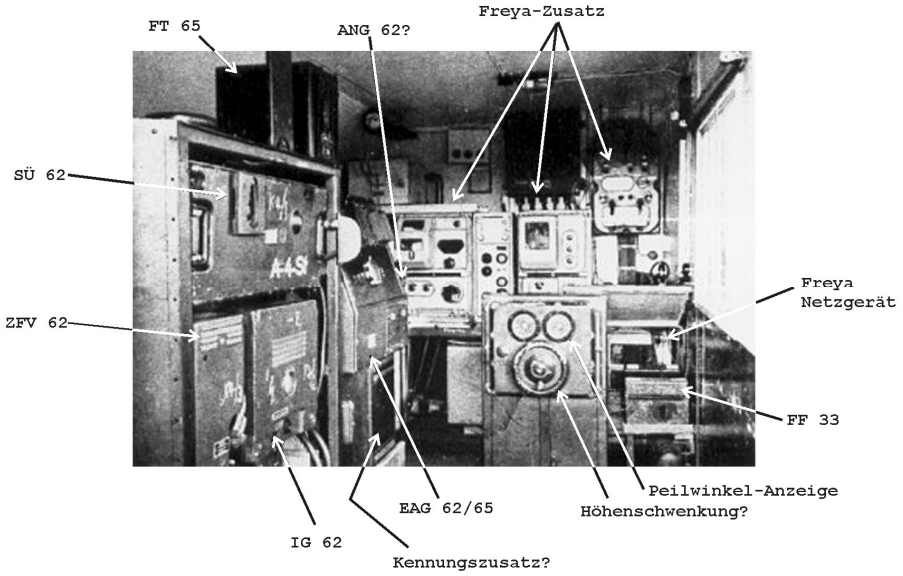


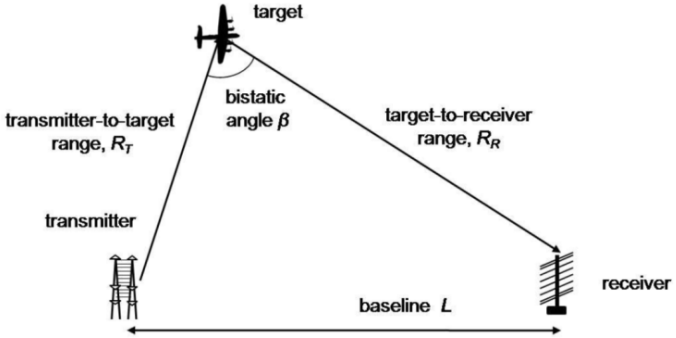
Figure 37. Rotary antenna—side view (cover removed).

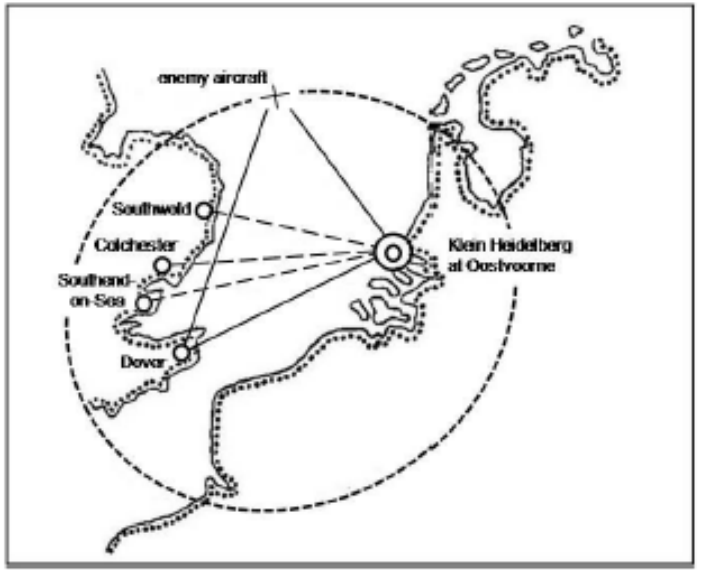


Wurzburg
RF 550-560 MHz
PRF 3750 Hz
PW 2µs
25Hz Conscan
Range 29km

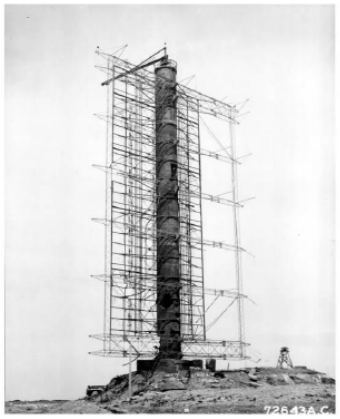
Klein Heidelberg – Bistatic "hitch-hiker" radar 1943-5

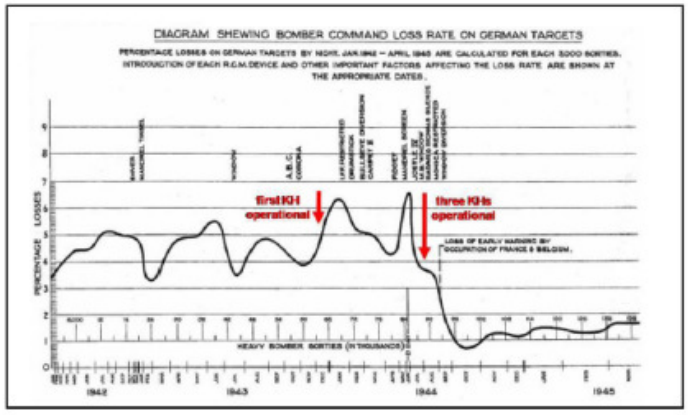
British Chain Home (CH) RDF
The Transmitter





Klein Heidelberg Receiver System
Omni to synchronise with Chain Home
Directional Antenna for echoes





- Ellipse formed by one Klein Heidelberg receiver using signals from one CH transmitter
- Accuracy and resolution similar to CH radar
- *Disrupted by jittering CH signals*

Klein Heidelberg – a WW2 bistatic radar system that was decades ahead of its time
Klein Heidelberg – the world"s first modern bistatic radar system", IEEE Trans. Aerospace and Electronic Systems, Vol.46, No.4, October 2010. Hugh Griffiths and Nicholas Willis,

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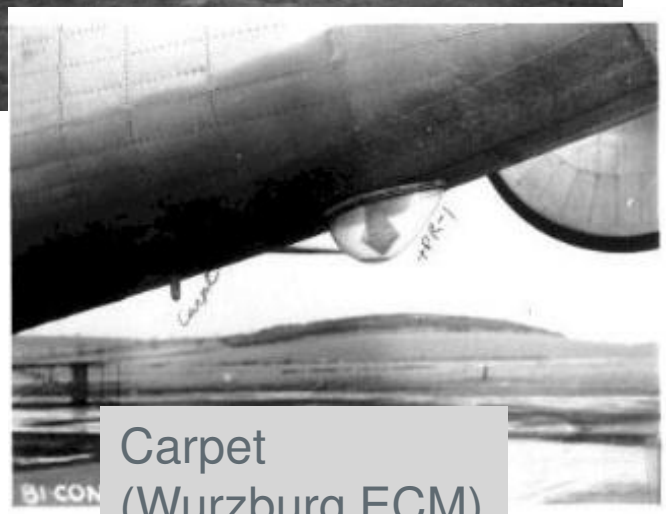
100 Group RAF – Bomber Support

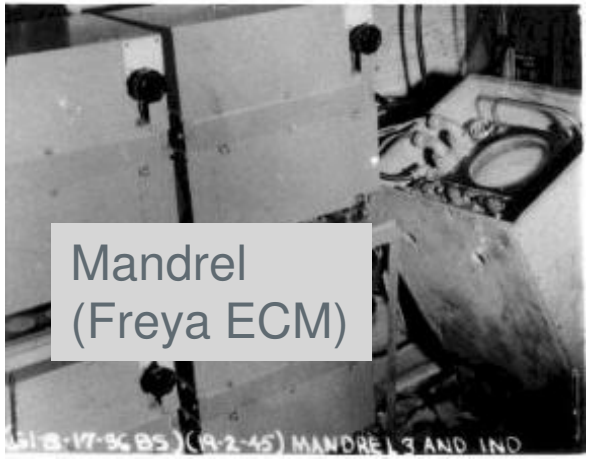
Boulton Paul Defiant
Moonshine & Mandrel
(Freya ECM)



Carpet
(Wurzburg ECM)

100 Group B-17
RCM Aircraft

Jostle
(Radio CM)



Mandrel
(Freya ECM)

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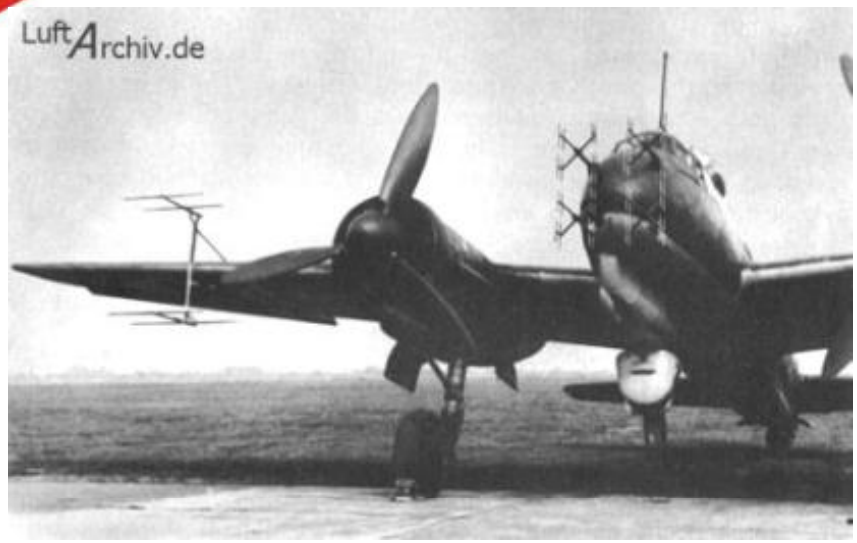
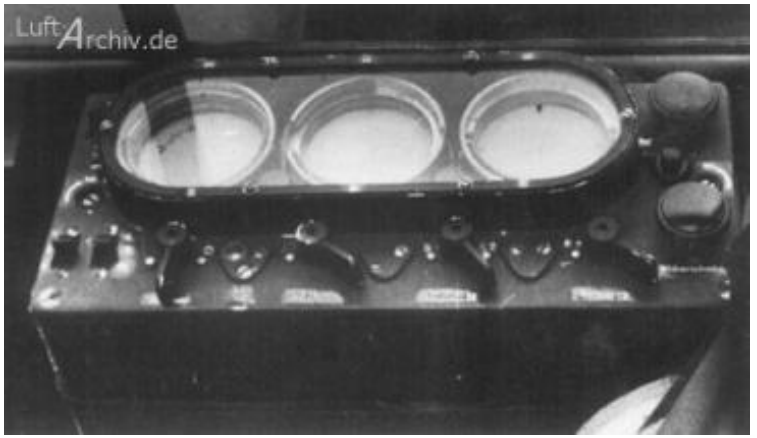
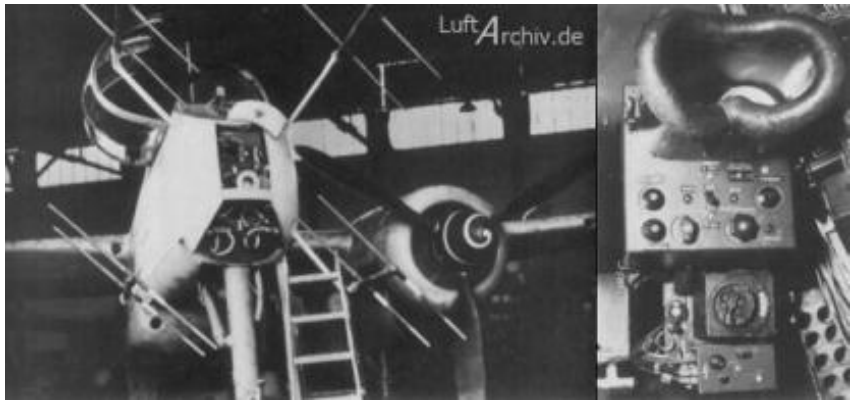
German Night-fighters - Lichtenstein AI Variants





FuG 212 C-1
RF 420-480 MHz



FuG 220 SN-2 RF 72-90 MHz

Boozer RWR on RAF Lancaster to detect C-1

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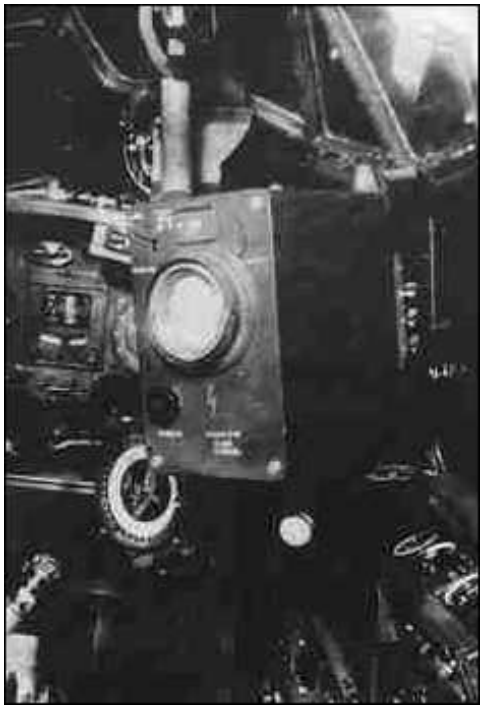
Monica and Flensburg FuG 227 RHWR

Monica
Tail Warning Radar
ARI 5664

RF: 300 MHz



Extract from TOP SECRET report on captured Ju88 G-1 in 1944

"A new installation for homing on to Allied Radar, (e.g. "Monica") is also installed, comprising a receiver and a cathode-ray tube indicator, designated the FuG 227.

The azimuth aerials for the FuG 227 are mounted projecting forward, toed out, from the leading edge of the port and starboard mainplanes, at a point approximately three-quarters distant from the fuselage in each case. The elevation aerials are located above and below the starboard wing slightly outboard and behind the azimuth position."

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Mosquito NF XII

AI Mk VIIIA Centimetric radar
Serrate RHWR for Lichtenstein C-1
Perfectos for Lichtenstein SN-2 & IFF

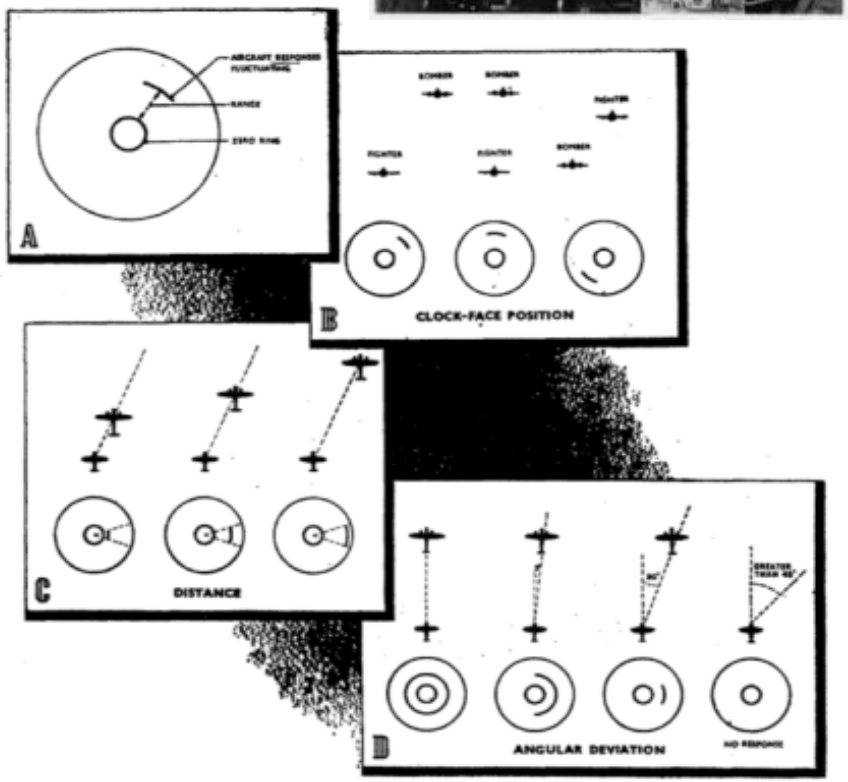
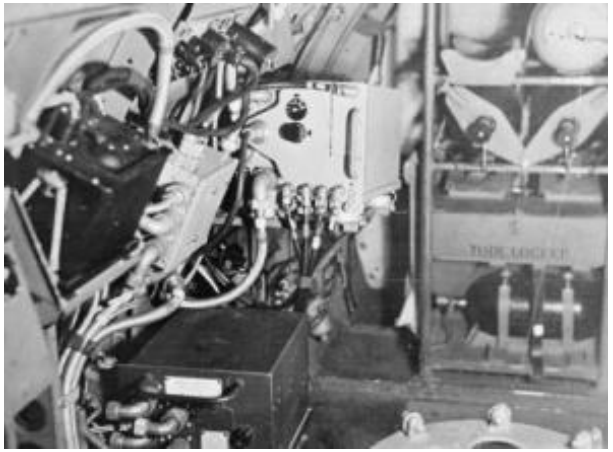
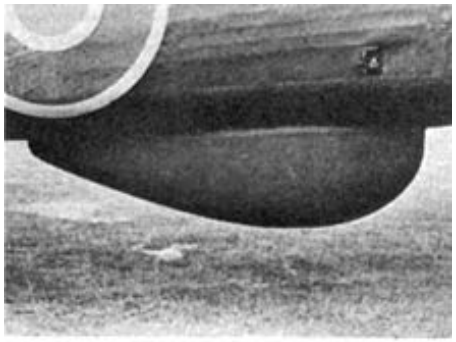


Fig. 13.—ARI. 5093 display system on AI

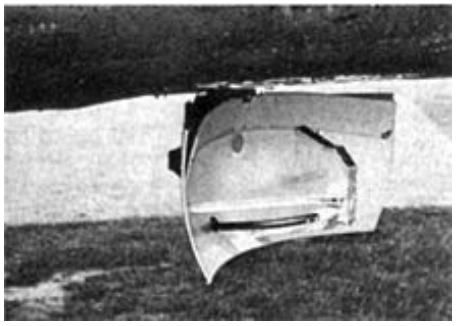


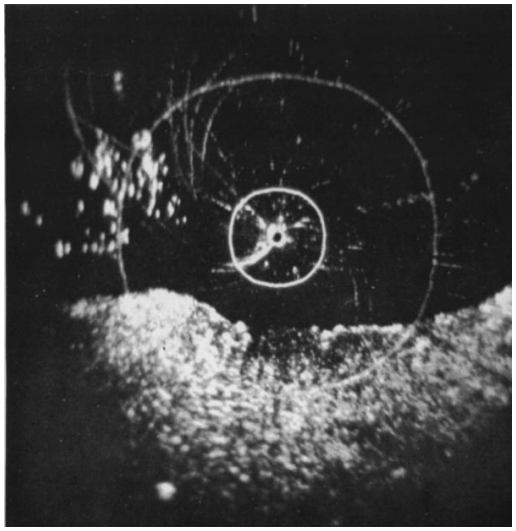
H2S Bombing/Navigation Radar

H2S
RF 3.3GHz
λ = 9cm

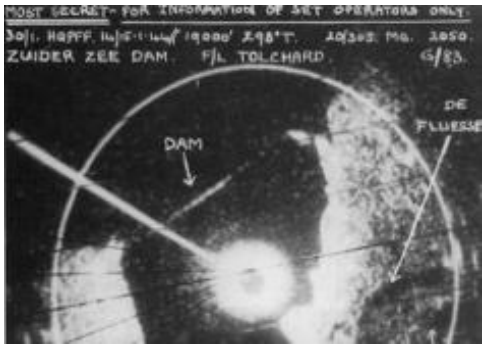


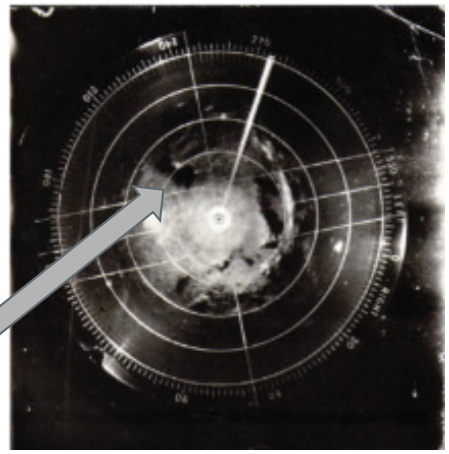
H2X
RF 10GHz
λ = 3cm



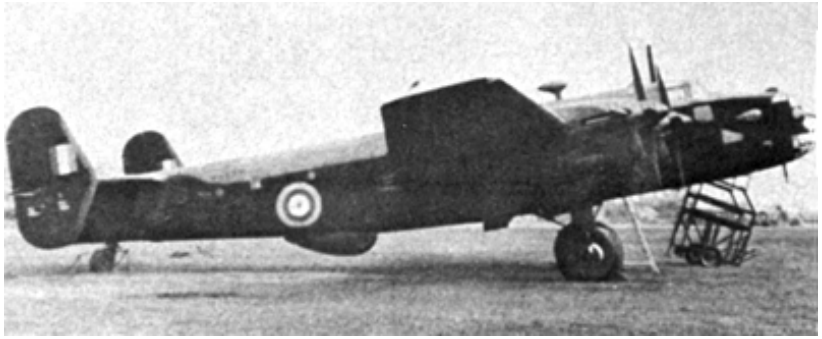


The picture was taken from the display of H2S on D-Day 6th June 1944. It shows the Normandy beach head a few minutes before the British and Canadian landing craft reached the Juno and Gold beaches. The town of Caen is the bright spot at '7 O'Clock'.





H2X over Mojave Desert
Edwards AFB and China Lake



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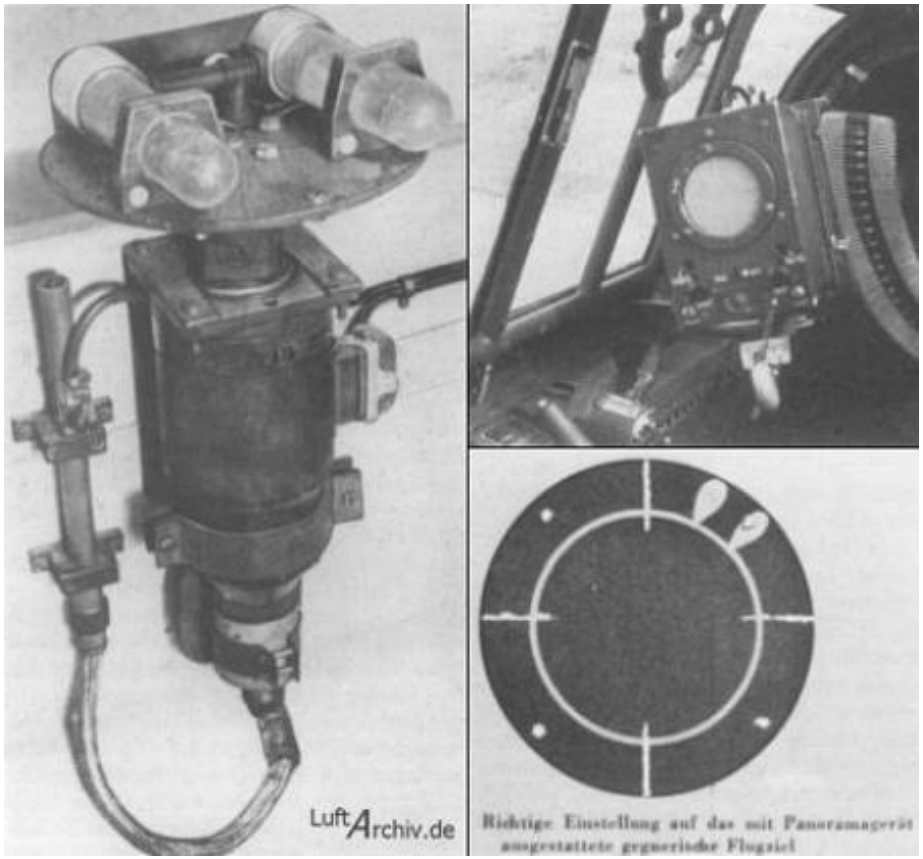
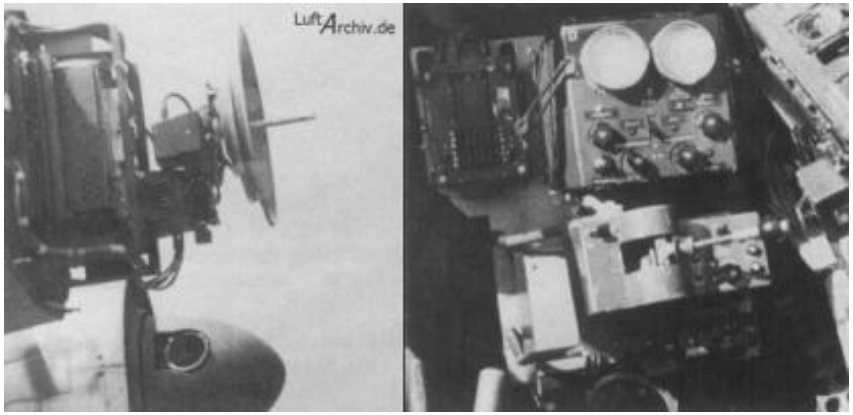
German response to Centimetric Radar

FuG 350 Naxos RHWR
RF 2.5-3.75 GHz





FuG 240 Berlin AI RF 3.3 GHz

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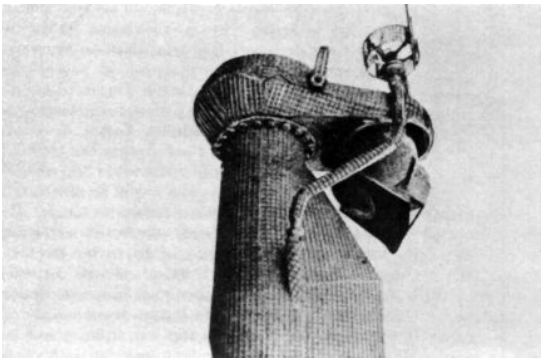
EW at sea

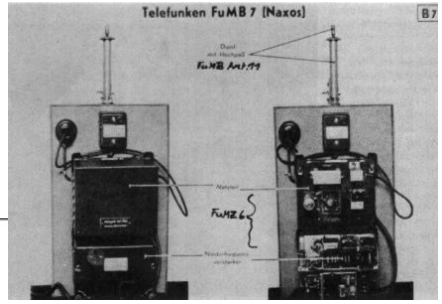
Wellington with centimetric ASH radar

B-24 with metric ASV radar

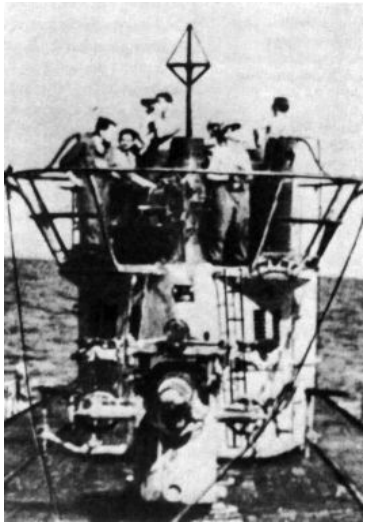


Schnorkel coated with “sumpf” RAM to reduce radar cross-section

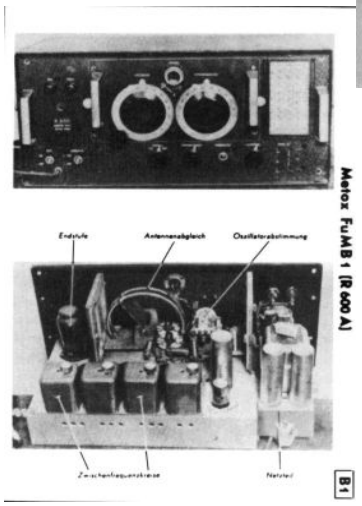
Naxos RWR

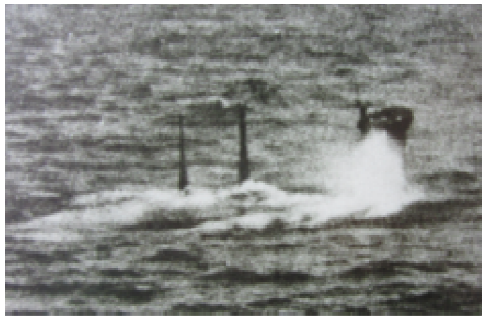


Schnorkel allowed U-boat to operate engines below surface



Metox RWR





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Fritz-X and Hs293

First used at Salerno in 1943

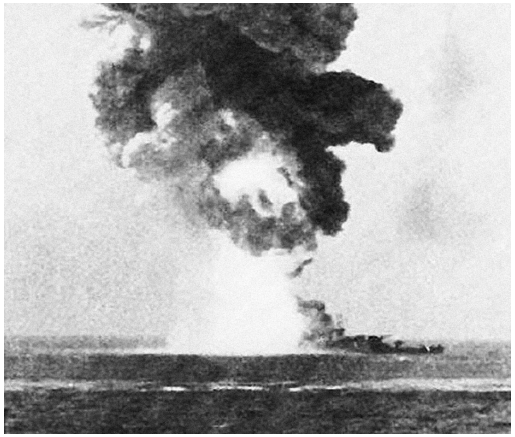
Hs293 Rocket Bomb

Kehl -Strassburg
Command Guidance Trainer

Fritz-X Guided Bomb

Radio Frequency Targeted by Countermeasures	Jamming Approach	Type of Jamming	
		Overwhelm Control Signal (Noise Jamming)	Insert False Control Signal (Spoofing)
Kehl Radio Signal (48–50 MHz)	Single Frequency (Spot) Jamming with Manual Tuning	XCJ XCJ-1 JCG Field system XCJ-2 (TX) ARQ-8	
	Single-Frequency (Spot) Jamming with Automatic Tuning	XCJ-3 (CXGE)	Type MAS
	Multiple Frequency (Barrage) Jamming	Jostle CNJ	
Intermediate Frequency (3 MHz)	Interaction of signal from fixed units at 48 MHz and 50 MHz	Type 650 Type 651	
Baseband Frequency (100 Hz)	Fixed at 50 Hz	Electrical razors	

Roma sunk by Fritz-X 1943



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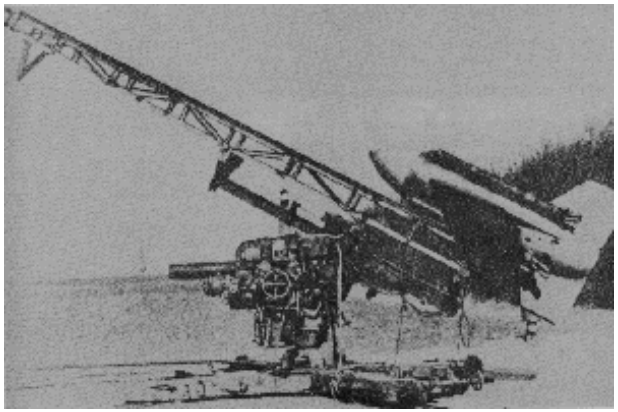
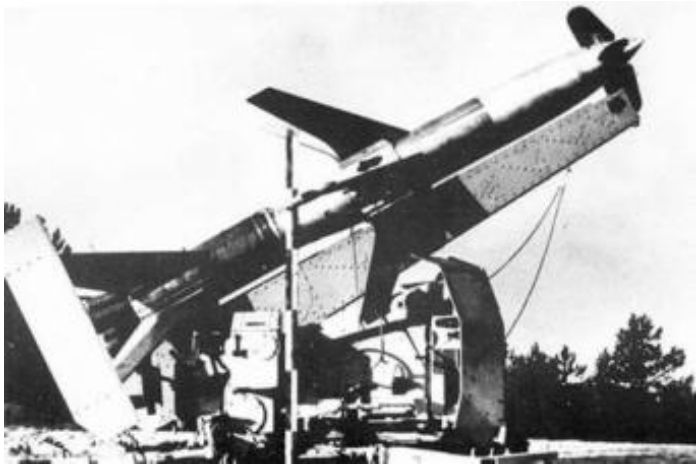
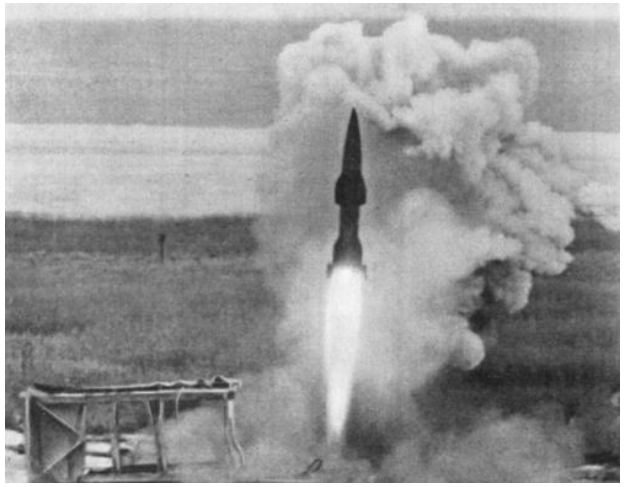
SAM – Surface-to-Air Missiles



Enzian
CG SAM with IR terminal homing
More like an unmanned aircraft



Rheintochter
Command-Guided SAM



Wasserfall
CG SAM

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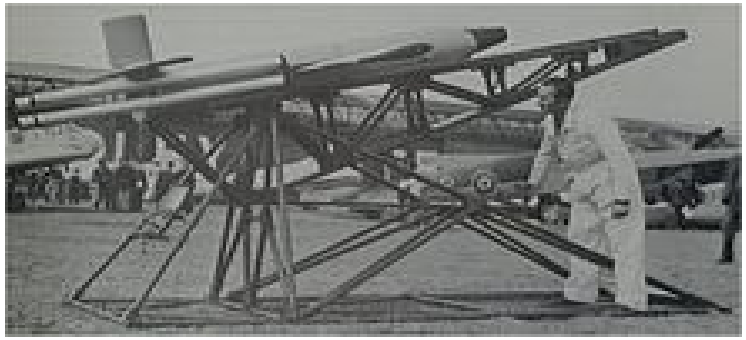
Russian, American and British 1st Generation SAM



Fairey Stooge
Radlett Airshow 1947

Bristol Bloodhound 1958
Ferranti Type 86 & Marconi Type 87 radars

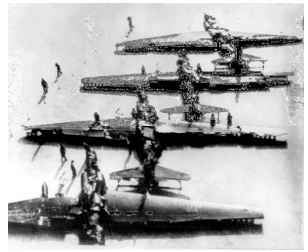
Nike Ajax 1954
S-25 Berkut 1955

English Electric Thunderbird 1959

1st May 1960 - The SAM Arrives – U2 and SA-2

U2 flown by Gary Powers shot-down over Russia, leading to major diplomatic incident

Actually the first "SAM kill" was an RB-57 on 7th October 1959, by a Chinese SA-2



4 U2 were apparently shot-down by China in1962-67

S-75 Dvina

SA-2 Guideline
Fan Song radar

Dual beam TWS

Still in service with many upgrades to capability

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British “V” Bombers

Victor - 1958
Valiant - 1955
Vulcan - 1957

Vulcan B2 – EW Fit

Name	Function
Green Palm	VHF Comms Jammer
Blue Diver	UHF Jammer
Red Shrimp (ARI 18076)	S-Band Jammer (~3GHz)
Red Steer (ARI 5919)	Tail warning radar
Blue Saga (ARI 18105)	RWR (replaced by ARI 18228)

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Lightning – AIRPASS – A.I. 23

- AIRPASS – Airborne Interception Radar and Pilot Attack Sight System
- World's first airborne monopulse radar, designed by Ferranti
- Self-contained "bullet" fairing suspended in engine air intake

- Variant "Blue Parrot" was fitted to Buccaneer aircraft

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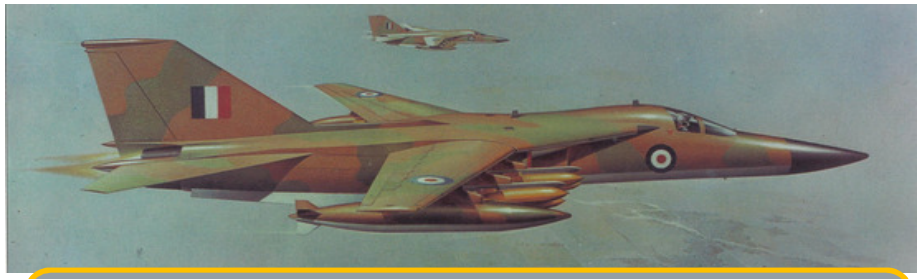
1964: Finances drive UK to Platform Collaboration

- TSR-2 and P.1127 - advanced designs
- Terrain-following radar and attack radar
- TSR-2 included a towed radar decoy in its EW system
- From this point in time, “platform” costs and programmes dominate decision-making despite avionics being one of the major cost-drivers

TSR-2 cancelled due to cost



F-111K replacement for TSR-2
Cancelled due to cost

P.1154 cancelled due to cost

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Vietnam 1964-1975

- 5.25 million sorties
- 1737 aircraft losses
- S-75 (SA-2) supplied by Russia
  - 1965: 1 kill per 10 missiles
  - 1972: 1 kill per 50 missiles

- RWR and jammers deployed
- EW operators were known as Ravens or Crows

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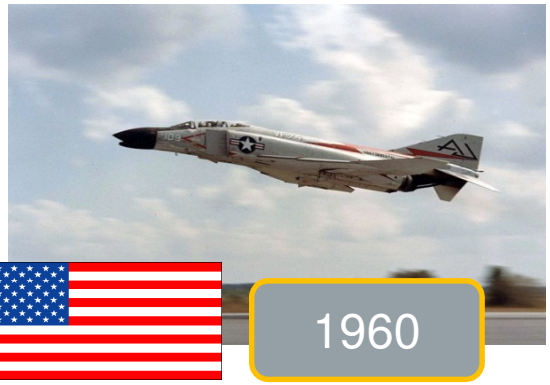
1964: F4 Phantom – Common Platform

- 12 user nations
- Primary US fighter and ground attack aircraft (all services)
- UK changed engines and avionics
  - Radar and EW collaboration between Westinghouse and Ferranti
- EW fits varied across nations and variants
  - UK had ARI 18223 and 18228
- US Wild Weasel V introduced new types of EW systems for SEAD role



1960

1969

Wild Weasel V - 1978

1971

1971

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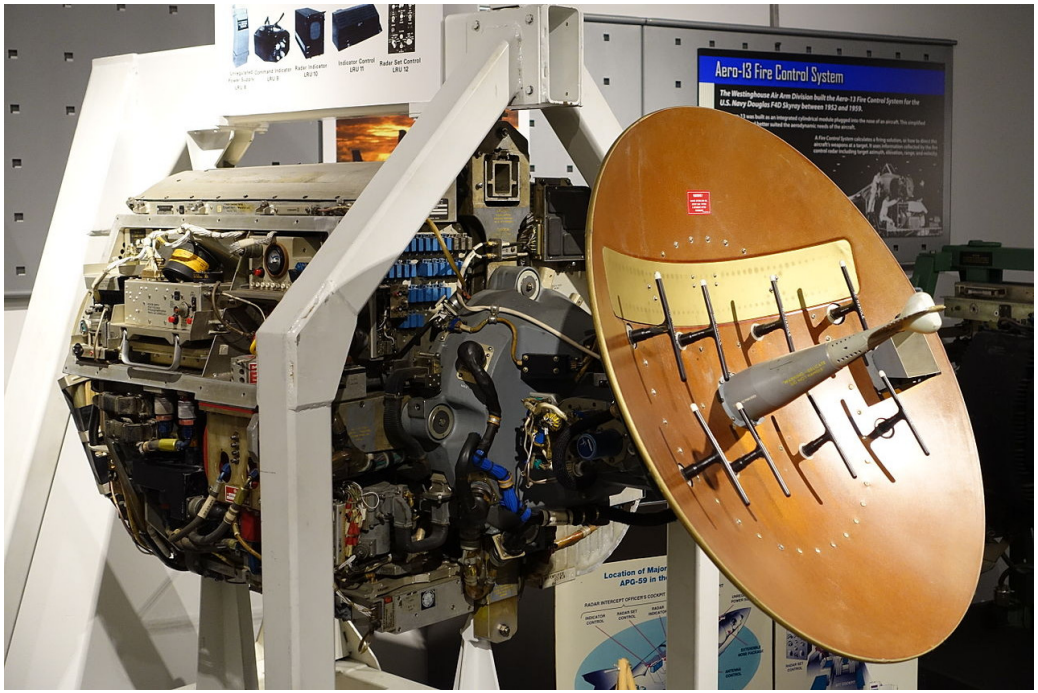
F-4 Phantom – AN/AWG 10 & 11

- Radar system designed in USA by Westinghouse
- Radar (e.g. AN/APG-59) includes IFF and CW Illuminator for Sparrow missiles
- Conscan tracking and FM-ICW ranging/velocity measurement
- Variants modified and maintained by Ferranti



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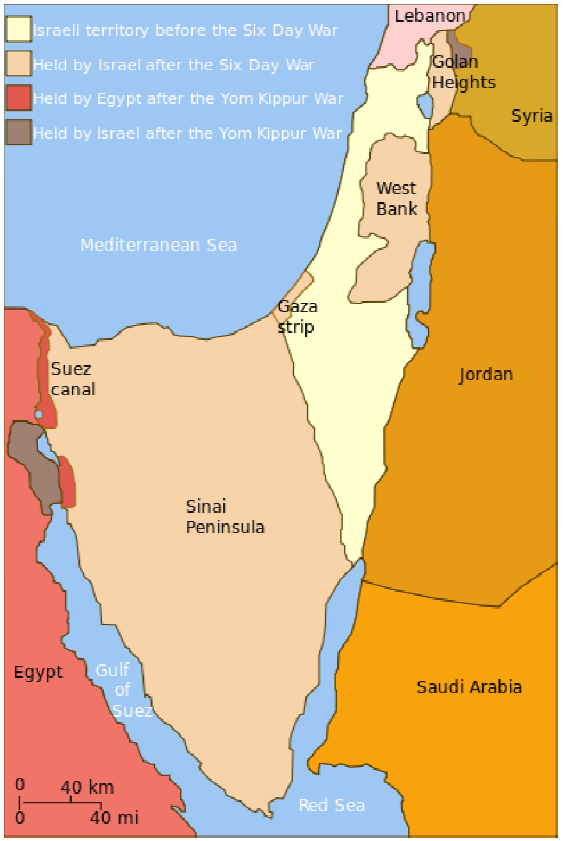
Middle East 1967 & 1973

- 1967: 6-day war
  - Israeli armour and airpower led to rapid victory
- 1973 October War (Yom Kippur)
  - Arab forces equipped with new Russian air defence systems (S-75 + SA-3, SA-6, SA-7 and ZSU 23-4)
  - Israeli air force seriously affected
  - Israeli tanks attacked by “Sagger” wire-guided missiles
  - US “crash programme” to develop ECM to new threats
    - SA-6 was first Warsaw Pact CW missile
    - 1 kill per 6 missiles at start
    - 1 kill per 33 missiles at end



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1964-1989: Harrier – Common Heritage

- Kestrel proved concept
  - Tri-nation trials unit
- Harrier GR1/3 and AV8A delivered the capability
  - Basic EW fit of Sky Guardian and chaff and flares
- Harrier GR5/7/9 and AV-8B matured the design
  - Different avionics and EW
  - UK Sea Harrier added Blue Fox radar
    - Upgraded to Blue Vixen
  - UK Harrier introduced integrated EW system (Zeus)

- Sea Harrier and Harrier GR 3 were used in Falklands war of 1982
  - "Black Buck" Vulcan raids used ARI 18228 RWR and ALQ 101-10 jammer
- A "crash programme" created the "Blue Eric" jammer that was fitted into the gun-pod of the Harrier GR3
  - Needed to counter Argentinian SkyGuard radars used with 30mm AAA
  - Took less than 3 weeks from requirement to make 9 systems
    - 6th May – 12th May 1982 from first discussion to prototype being tested

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Airborne Early Warning Radars

- Shackletons acted as stand-ins after FAA Gannets were withdrawn
- Then there was Nimrod AEW ....
- Then the American AWACS was purchased

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1989: Tornado - European Collaboration

- Common platform to meet Strike Aircraft requirements
  - Basic fit was GMR/TFR nose radar
- National variants for Fighter (UK) and SEAD (Germany & Italy)
  - Different radars and mission avionics in these variants
- EW fit specified by nations
  - Different RWR and ECM systems, different support solutions
  - UK Tornado GR1 & GR4 fitted with RHWR, Skyshadow and BOZ chaff and flare dispenser
  - UK Tornado F2 & F3 had original RHWR with interferometer arrays - fitted with BOZ Towed Radar Decoy pod in 1995
- Used in coalition operations from 1990 to present day

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Tornado F2/3 ADV - A.I. 24 – a.k.a. Foxhunter

- ICW radar with CW for semi-active illumination for missiles
- Monopulse angle measurement
- Twist-cassegrain antenna to reduce mass of scanner
- Designed by Marconi

- *Early problems led to "Blue Circle" installation*

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Gulf War 1990-91

- Tornado was main British aircraft involved in first Gulf War
  - RHWR and Skyshadow on GR1
  - Formation jamming response to defeat SA-8
- Coalition forces deployed special forces and attack helicopters to defeat Iraq integrated air defence system
- First use of stealth aircraft (F-117)

The Balkans – Break-up of Yugoslavia

- Balkan operations brought NATO into contact with an imaginative opponent
  - Clever use of SA-6 to shoot down Scott O'Grady's F-16
  - Clever use of SA-3 to shoot down F-117
- RAF deployed Tornado F3, GR4 and Harrier GR5
  - New EW tactics were very successful
  - Towed Radar Decoy deployed on F3
- Some interoperability issues affected NATO forces

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1989-2014: Typhoon – Common platform and avionics

- Collaboration to meet common requirements and cost control
- Same radar and baseline EW fit
- Industrial consortia
  - EuroRadar & EuroDass
- National control of EW data and some software
- Effective in Libyan operation

S-75 (SA-2) again!

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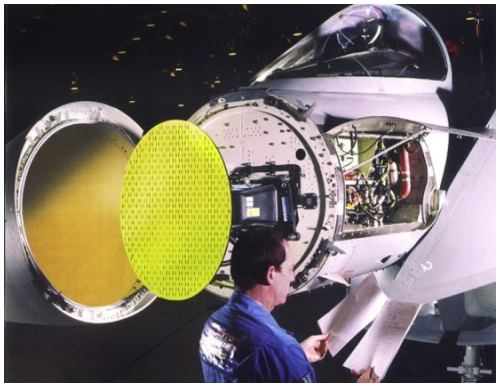
Typhoon – Captor

- Multi-mode radar – designed by Ferranti / GEC (now Selex)
  - Some similarities with Blue Vixen on Sea Harrier
- Current version is a flat-plat, slotted-array antenna
- High, medium and low PRF modes with FM, Pulse Doppler and Pulse Compression
- New version is active electronically-scanned
  - using banks of phase-shifting TR Modules



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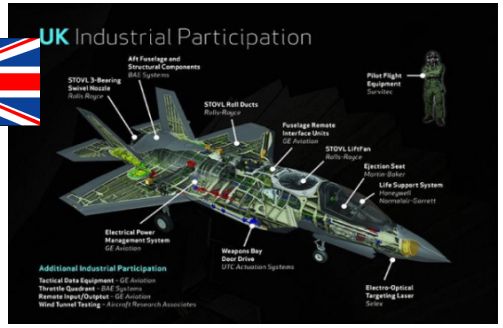
2014: F-35 – Shared Industry and Information

- F-35 meets many operational needs of its many users
  - Cost-sharing a major driver for all nations
  - Political imperative to show national industrial involvement
- Information and Interoperability is key for NCO/NEC
  - Will operate alongside Typhoon and Tornado in UK and Italian air forces
  - Need to ensure that they will have common Situation Awareness and can collaborate in the EM spectrum



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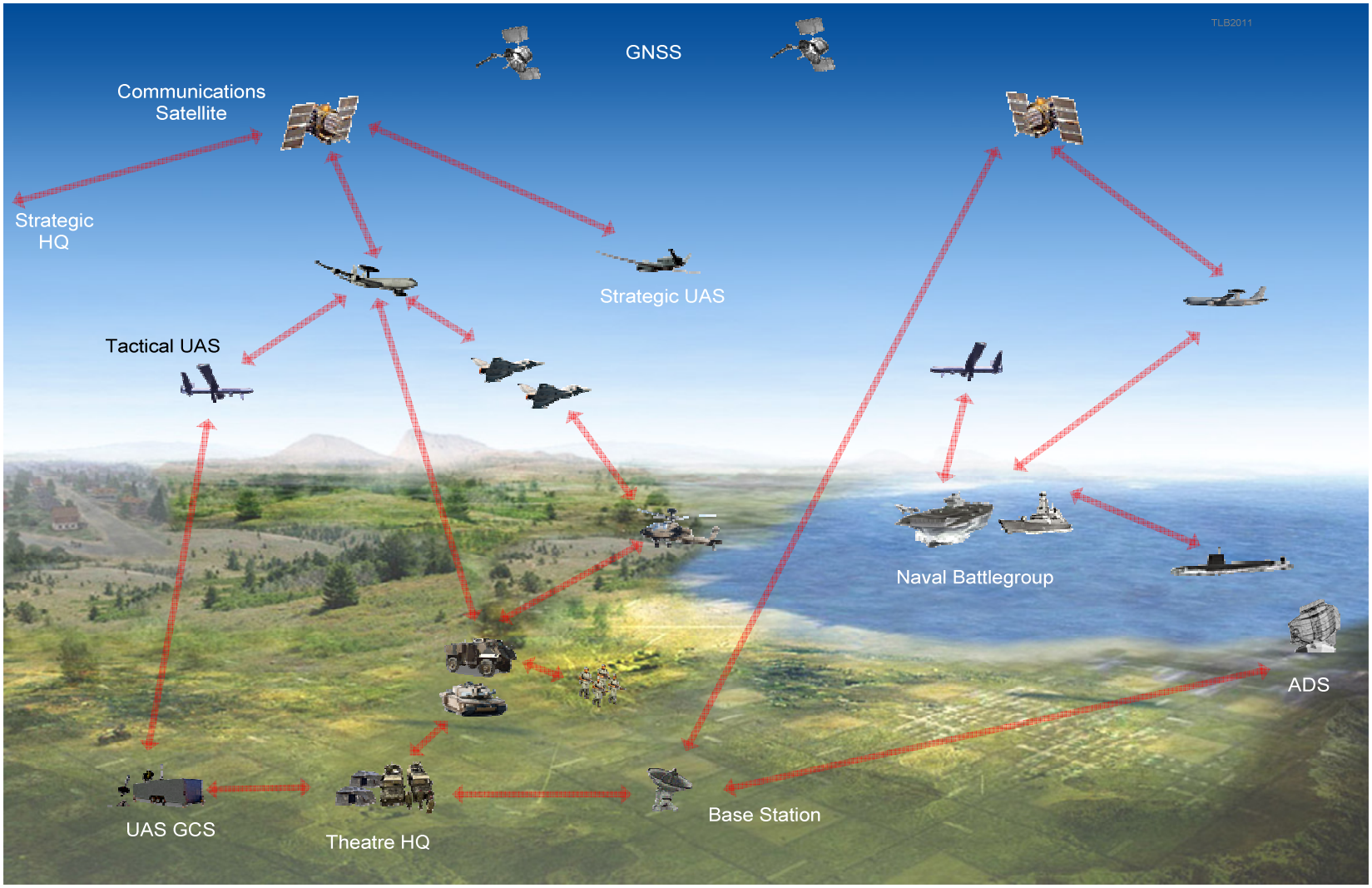
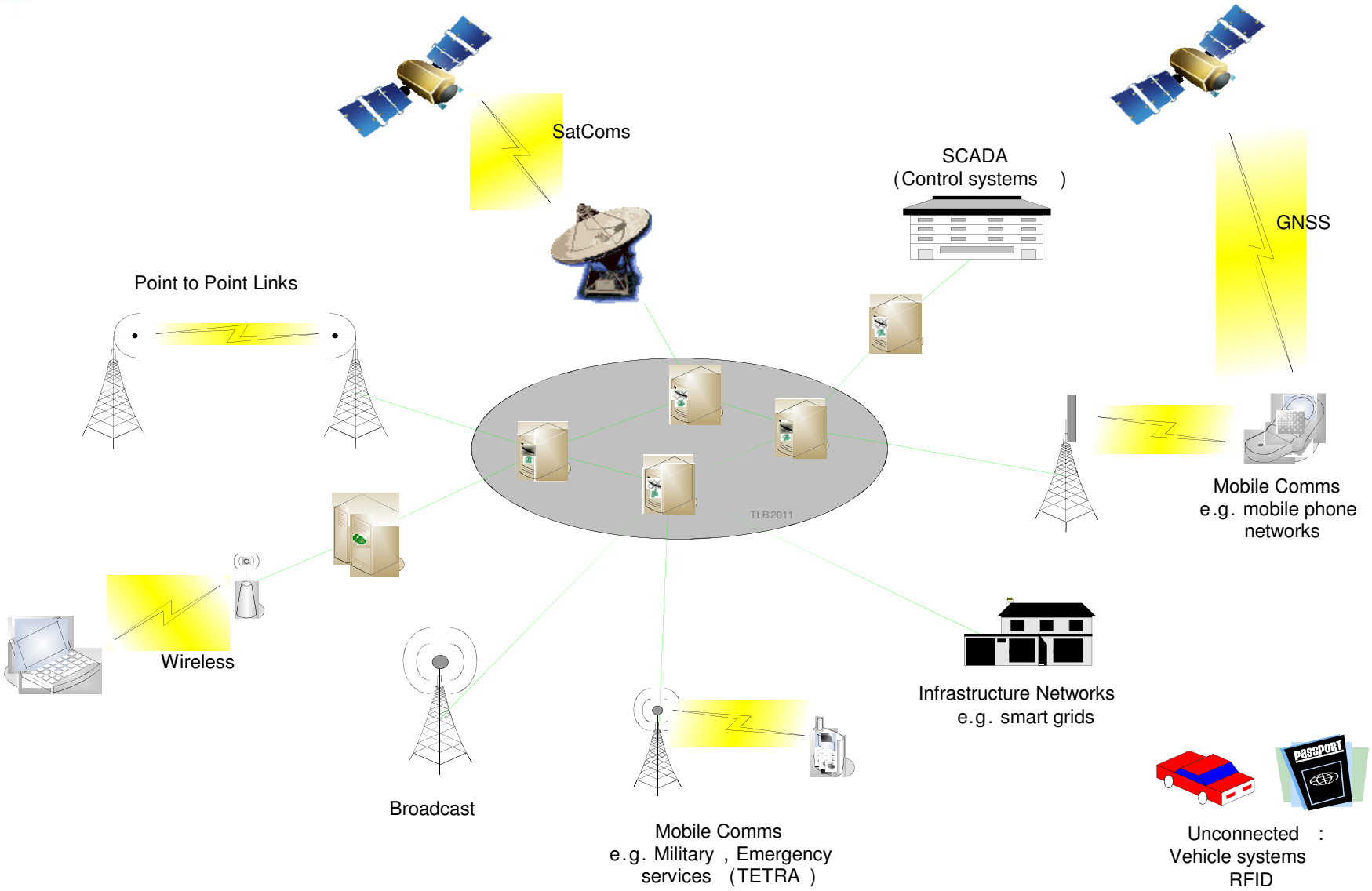
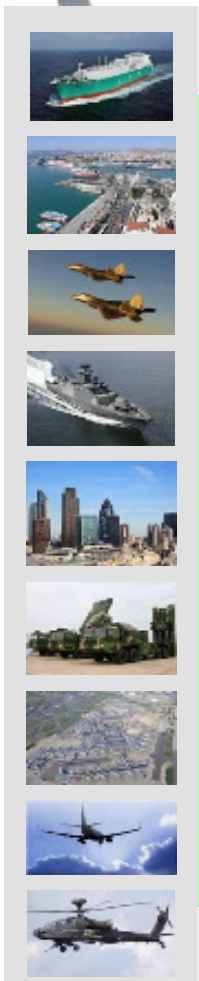
Military Operational Networks



Civil Operational Networks



The EMS OODA Loops



Real World
Data World

Data World
Cognitive World

Information

Electromagnetic
Spectrum
& Physics

Radar
Cameras
EW

Observe

Orient

Data fusion
Picture compilation

Knowledge

Communications
&
Information networks

EW
Weapons
Manoeuvre

Act

Decide

Mission planning
Decision support

Commands

EW is unique in the EMS as acting as a source of information (sensor) and as an effector (jamming and disinformation)

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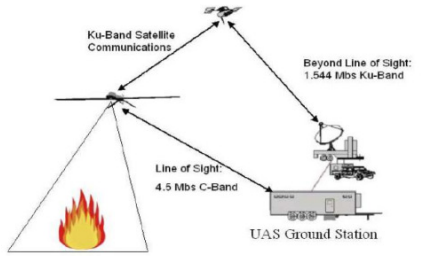
An example of the new EW challenge

UAV – an exemplar of information warfare

- **We rely on UAV to operate as surveillance assets and to perform some kinds of attack**
  - We may also need to be able to defend ourselves from UAV

- **To maintain operational advantage in the physical domains, we must protect freedom to manoeuvre in the Electro-Magnetic Environment**
  - We rely on “MOTS” to provide navigation and the connectivity to the UAV
  - The UAV is inherently “noisy” in the EME
  - Some of its sensors are vulnerable to relatively simple counters
  - Many internet sources refer to “How to kill UAV”



- **We need to develop “Protection of Information & Bandwidth” as well as “Protection of the Platform”**
  - The Frequency Bands of interest are wide!

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Summary

- Electronic Warfare is how we maintain Operational Advantage and Freedom of Action in the Electromagnetic Environment:
  - Determine enemy use of Electromagnetic Spectrum
  - Degrade or prevent enemy use of Electromagnetic Spectrum
  - Maintain friendly ability to use Electromagnetic Spectrum

- 1914-1939 dominated by radio interception, with some jamming
- 1939-45 air war brought new challenges and technological advancements
  - RADAR, SIGINT, ELINT, RCM, ECM, RWR, AI, GCI, IR, SAM. RAM
- 1964-1989 Cold War saw the deployment of assets in “proxy wars”
  - New threats and new EW
- 1989-2014: unexpected interventions in Balkans and Middle East
  - Emphasis shifted to protection of helicopters and other assets

- The big issue for the future is the increased use of networks
  - We must continue to provide sensors working in the electromagnetic spectrum
  - We must continue to protect platforms
  - We must add protection of information and bandwidth