1.2 *Stealth and Counterstealth*

1. Historical background
2. Radar Absorbing Material (RAM)
3. Sensor signatures
4. Bistatic radar
5. Low frequency radar
6. Impulse radar

Stealth

There has been much media interest in stealth and stealthy aircraft in the past ten years or so, and claims are made that such targets are ‘invisible to radar’. Not surprisingly, much of this is rubbish !

This section looks at the techniques used to reduce the radar signature of targets, the reduction in detection performance that this gives, and some of the radar techniques that might be used to recover the advantage that reduction of the target signature has brought.

Stealth

Stealth is not one, but an assemblage of techniques, which makes a system harder to find and attack.

- Force the threats to use active sensors sparingly by employing antiradiation missiles and electronic countermeasures
- Decrease predictability and increase ‘randomness’ to force the threats to increase complexity and cost of intercept receivers, surveillance, fire control, and missiles
- Reduce active and passive signatures and increase ‘hiding’ to make weapon systems less visible
- Use tactics that combine with the order of battle as well as the natural and man-made environment to enhance the effect of the reduced observables
- Use prior knowledge and off-board sensor cueing to minimize on-board active and passive exposure

Lynch, D. Jr. *Introduction to RF Stealth*; SciTech/IEE, Raleigh NC, 2004.

Sir Robert Watson-Watt

Camouflaging of aircraft at centimetre wavelengths
(27 August 1941)

‘The simplest theoretical way of matching an aircraft to free space is to envelop it in a resistive skin whose surface-resistivity is 377 ohms, and to maintain an air-gap between skin and aircraft of a quarter of a wavelength. …

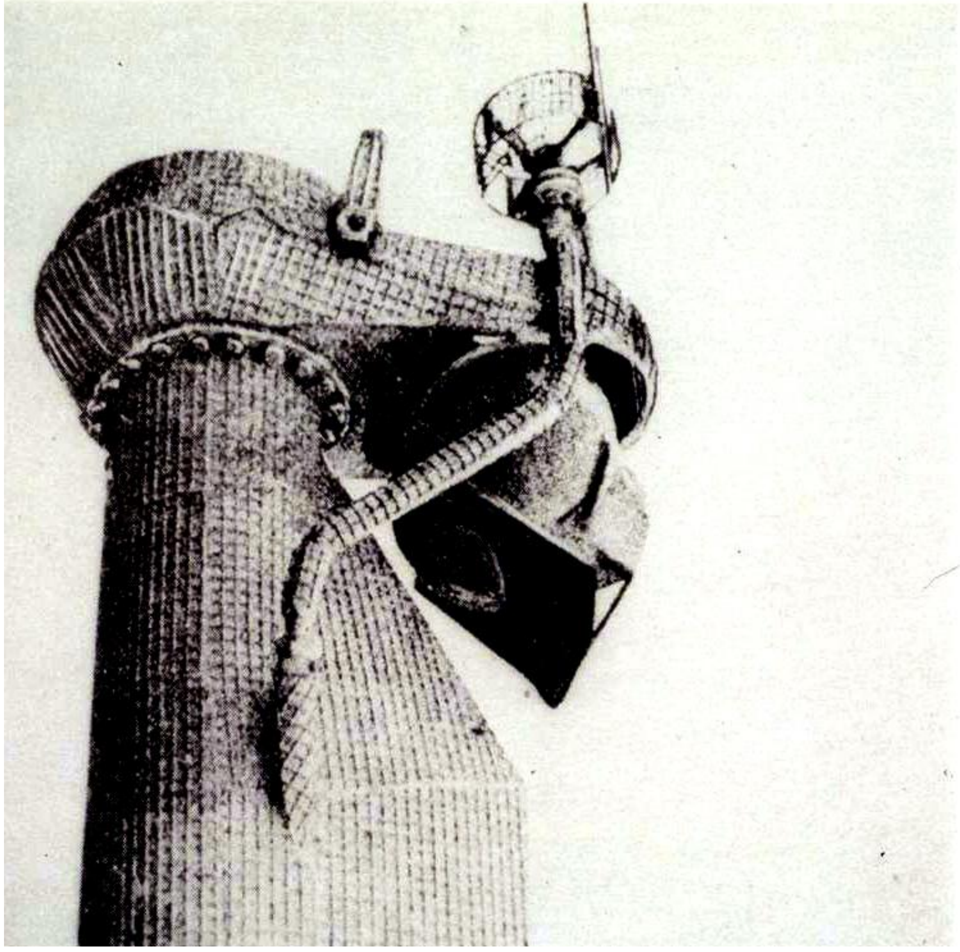
... The gap between skin and aircraft may be considerably reduced by filling it with a medium in which the wavelength is less than in free space. …

… To obtain a large bandwidth we need to use a medium of low conductivity with a high ratio of permeability to dielectric constant. If this ratio is 4, the intrinsic resistance of the medium is

$$R = \sqrt{4} \times 377 \quad = 750\ \Omega$$

… It is concluded that there is a real scientific possibility of camouflaging an aircraft over a limited frequency-range at centimetre wavelengths. How far large-scale use of such camouflaging may be feasible or useful is for others to decide.’

Earliest operational use of RAM on WWII German U-boats (1944)



A Schnorkel tube covered with 'Sumpf'. This reduced radar returns to some extent but it soon became detached from the U-boat's structure by wave action, and salt deposits reduced its electrical effectiveness. The small dipole is the aerial for Tunis; it gave a good echo to 3-cm radars.

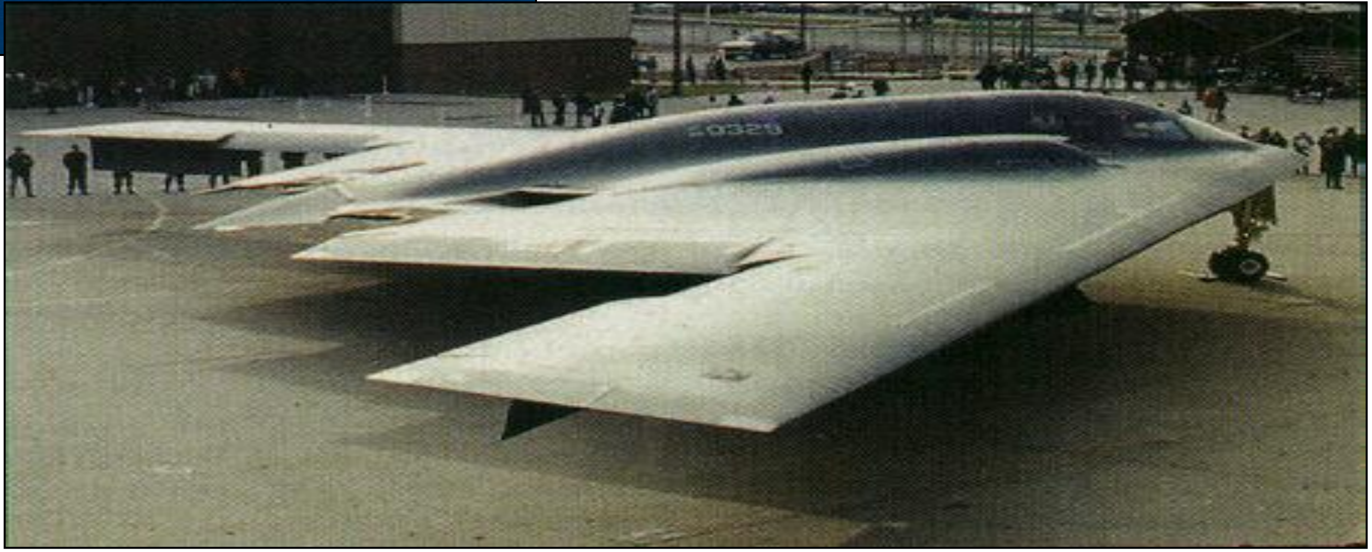
source : Barry Chambers, University of Sheffield

Stealth techniques

There are several techniques that are used to reduce the radar signature of a target:

- cover the surface in Radio Absorbing Material (RAM)
- use RF-transparent composite materials
- shape the target to reduce edges, surface discontinuities and corners (dihedrals or trihedrals)
- shape the target to reflect radiation in directions other than that of the radar

Stealth techniques



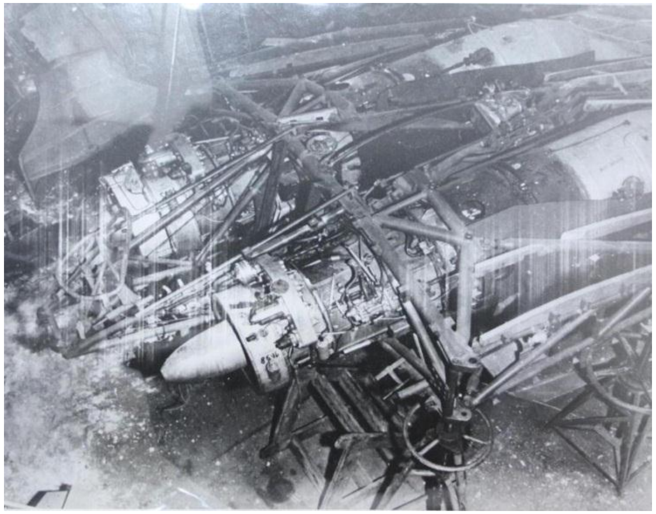
B-2

B-2

Northrop XB-35 (1946)

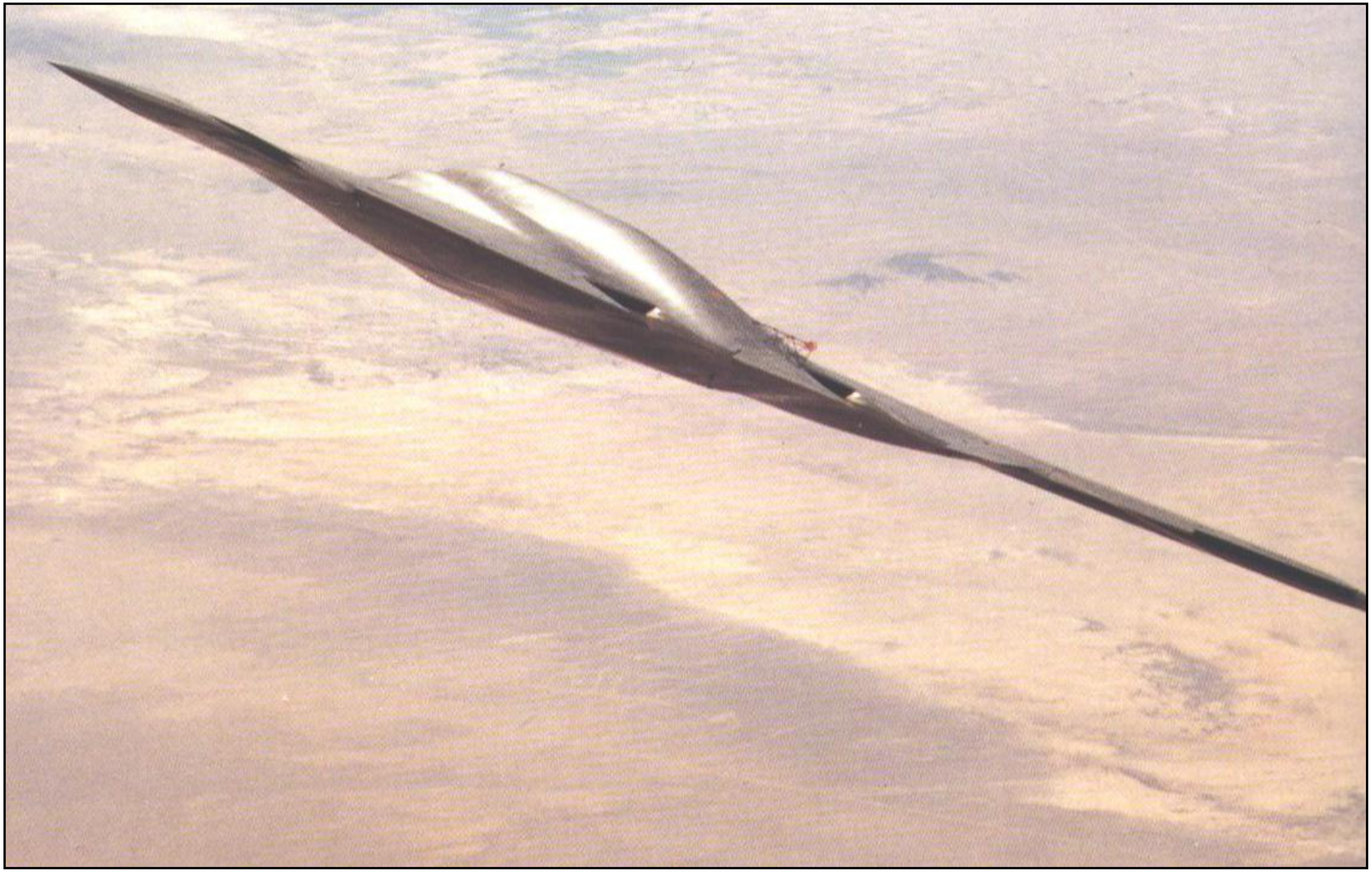
Northrop YB-49 (1947)

Horten Ho 2-29



Horten Ho 2-29

B-2



B-2

B-2

F-117A

F-117A

F-117A

source : http://www.fas.org

De Havilland Mosquito

Largely constructed from wood but metal parts (engines) could still be seen by radar

source : Barry Chambers, University of Sheffield

Stealth techniques

The ability to accurately predict the RCS of targets of a given shape and material is clearly central to the ability to reduce the radar signature of a target. This has depended critically on the development of electromagnetic models and software to allow this to be done, within the constraints of computing resource, and huge effort has been expended on doing this.

Also, aircraft designed to have a low radar cross section tend not to be very aerodynamically stable !

So it is only the development of sophisticated control systems that can actively maintain the aircraft in flight that makes aircraft stealth practicable.

Stealth techniques

Table 1.6 First Order Specular RCS Components[12]

Scattering source	Type of scatter	Approx. RCS equation $(m^2) \bullet \Gamma^2$	Approx. beam width (°)	Approx. peak angle (°)
Flat plate	Broadside	$4\pi A_e^2/\lambda^2$	$(57.3\lambda/L_{eff})^2$	$\theta = 0$
	Front edge	L_{eff}^2/π	$(57.3\lambda/L_{eff}) \times 360°$	$\phi = 0$
	Back edge	$< L_{eff}^2/\pi$	$(57.3\lambda/L_{eff})^2$	$\phi = 0,\ \theta = 49(\lambda/L_{eff})^{0.5}$
	Tips	$\lambda^2 \tan^4 \alpha/(16\pi)$	omni	all ϕ and θ
Cylinder	Broadside	$2\pi a L_{eff}^2/\lambda$	$(57.3\lambda/L_{eff}) \times 360°$	$\theta = 0,\ \phi = 0$
	Edges	$a_e \lambda/(2\pi)$	omni	all ϕ and θ
	Trailing rim edge	$\pi\lambda a^2/L_{eff}$	$(57.3\lambda/2a)^2$	$\theta = 0,\ \phi = \pm 90$
	End	$4\pi^3 a_e^4/\lambda^2$	$(57.3\lambda/2a_e)^2$	$\theta = 0,\ \phi = \pm 90$
Cone	Broadside base	$4\pi^3 a_e^4/\lambda^2$	$(57.3\lambda/2a_e)^2$	$\theta = 180,\ \phi = \text{any}$
	Broadside cone	$8a_e^2/(9\sin^2\alpha \cdot \cos\alpha)$	$(57.3\lambda/2a_e) \times 360°$	$\theta = \alpha,\ \phi = \text{any}$
	Trailing rim edge	$\pi\lambda a \cdot \tan\alpha/2$	$(57.3\lambda/2a)^2$	$\theta = 0,\ \phi = \text{any}$
	Tip	$\lambda^2 \tan^4 \alpha/(16\pi)$	omni	all ϕ and θ
Ogive	Broadside @ surface normal	$\pi r_1^2(1 - \cos\ \alpha/\sin\theta)$	$(90° - \alpha) \times 360°$	$\theta = (90° \pm \alpha), \phi = \text{any}$
	Trailing rim edge	$\pi\lambda a^2/L_{eff}$	$(57.3\lambda/2a)^2$	$\theta = 49(\lambda/L_{eff})^{0.5}, \phi = \text{any}$
	Tip	$\lambda^2 \tan^4 \alpha/(16\pi)$	omni	all ϕ and θ
Egg (spheroid)	Broadside @ surface normal	$\pi r_1 r_2$	omni	all ϕ and θ
Untreated cavity	Hole	$2A_e \cos^2\theta$	$60°^2$ typical	$\theta = 0,\ \phi = \text{any}$
	Edges	L_{eff}^2/π	$(57.3\lambda/L_{eff}) \times 360°$	$\phi = 0,\ \theta = \text{edge normal}$
Dihedral	Broadside	$8\pi a_I^2 b_I^2/\lambda^2$	$90°^2$	$\theta = \pm 45°,\ \phi = \text{most}$
	Edges	L_{eff}^2/π	$(57.3\lambda/L_{eff}) \times 360°$	$\theta, \phi = \text{edge normal}$
Wire	Broadside	L_{eff}^2/π	$(57.3\lambda/L_{eff}) \times 360°$	$\theta, \phi = \text{edge normal}$
Wire loop	Broadside	πa^2	$(57.3\lambda/2a)^2$	$\theta = 0,\ \phi = \text{any}$

Note: λ is the wavelength, L_{eff} is the effective length, a is the radius, a_e is the effective radius, a_I and b_I are the side lengths, α is the cone or edge half angle, A_e is the effective area, and ϕ and θ are the usual spherical coordinate angles assuming that z is normal to the surface or edge.

Lynch, D. Jr. *Introduction to RF Stealth*; SciTech/IEE, Raleigh NC, 2004.

Stealth techniques

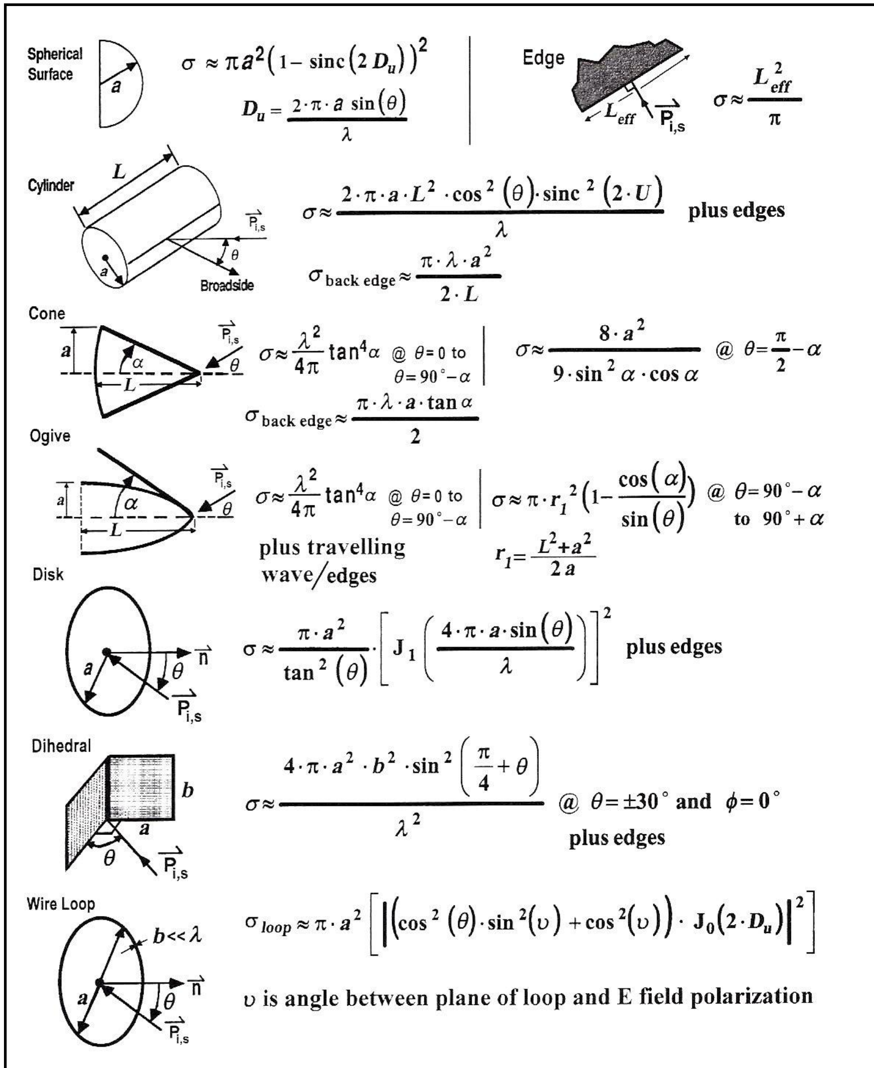


Figure 1.20 Summary of second-order RCS approximations.

Lynch, D. Jr. *Introduction to RF Stealth*; SciTech/IEE, Raleigh NC, 2004.

Radar Absorbing Material (RAM)

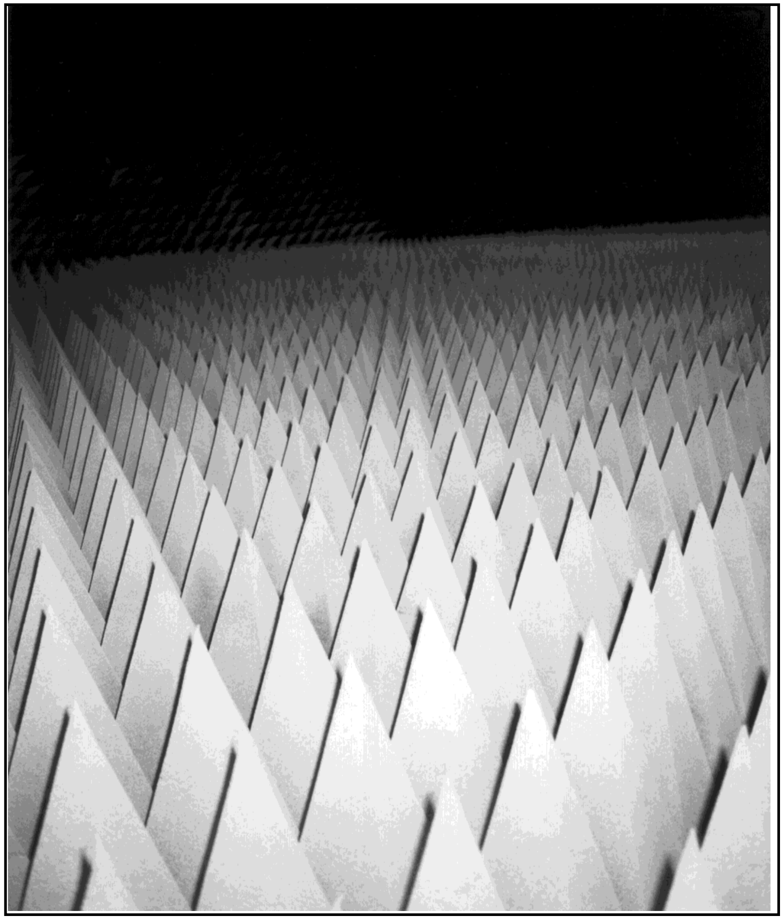
Essentially a matter of designing materials to present a particular impedance to an incident electromagnetic wave.

The Fresnel equations for the reflection coefficients at the boundary between free space and a semi-infinite medium are:

$$\Gamma_{||} = \frac{\left(\mu_r \varepsilon_r - \sin^2\theta\right)^{1/2} - \varepsilon_r \cos\theta}{\left(\mu_r \varepsilon_r - \sin^2\theta\right)^{1/2} + \varepsilon_r \cos\theta} \qquad \Gamma_{\perp} = \frac{\mu_r \cos\theta - \left(\mu_r \varepsilon_r - \sin^2\theta\right)^{1/2}}{\mu_r \cos\theta + \left(\mu_r \varepsilon_r - \sin^2\theta\right)^{1/2}}$$

which are a function of angle of incidence θ and polarisation, as well as material properties μ_r ,ε_r.

Radar Absorbing Material (RAM)



Radar Absorbing Material (RAM)

Better performance can be obtained by coating a metallic surface with a layer of dielectric material. The normalised input impedance is given by :

$$\eta = \sqrt{\mu_r / \varepsilon_r}\,\tanh\left(-\,jk_0 d\sqrt{\mu_r / \varepsilon_r}\right)$$

Then the reflection coefficient *R* is given by :

$$R = \frac{\eta - 1}{\eta + 1}$$

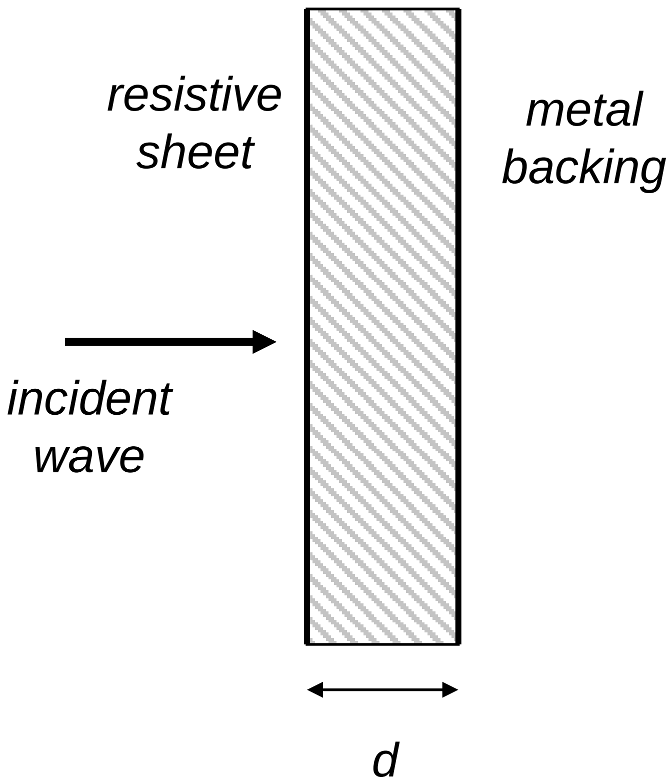
or

$20\log_{10}R$ (dB)

Salisbury Screen

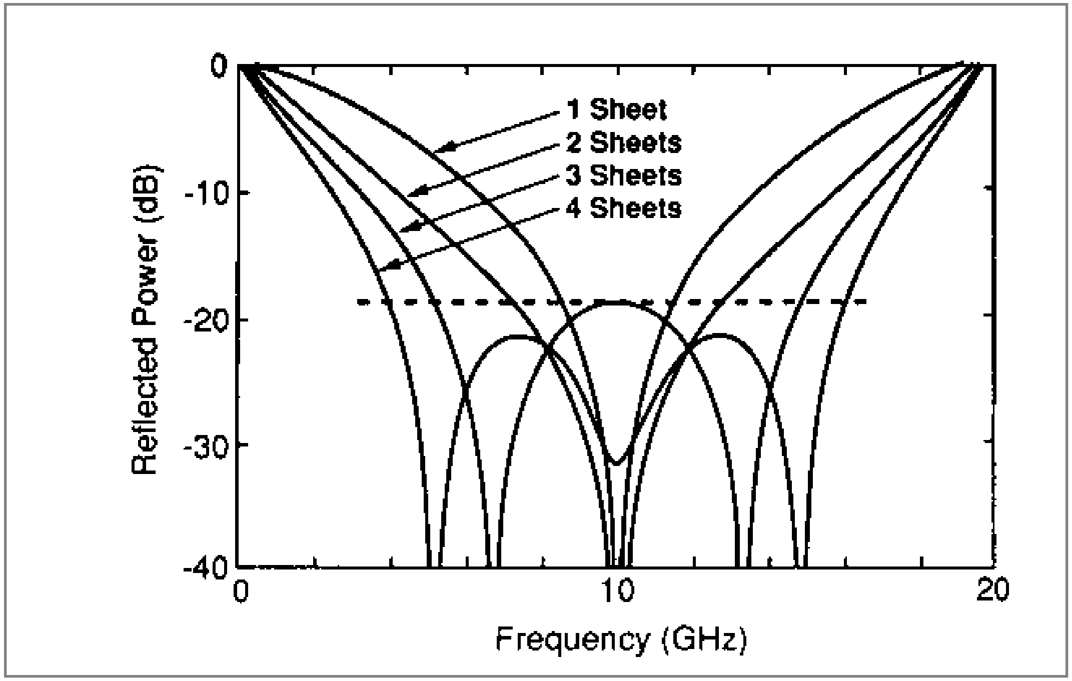
One of the oldest types of absorber consists of a resistive sheet spaced in front of a metal sheet by a low dielectric constant spacer (plastic foam or honeycomb)

For zero reflectivity the Salisbury screen requires a resistive sheet of 377Ω/sq (i.e. matched to free space), spaced by an odd multiple of a quarter wavelength



Jaumann absorber

The bandwidth of a Salisbury screen can be improved by adding additional resistive sheets and spacers. For best performance the resistivity of the sheets should vary from a high value for the front sheet to low value for the back. The bandwidth depends on the number of sheets used – this can give good performance over fractional bandwidths greater than unity, but the overall thickness increases.



La Fayette

source : http://www.fas.org

Visby

Visby

Type 45

Sea Shadow

source : http://www.fas.org

Stealth techniques

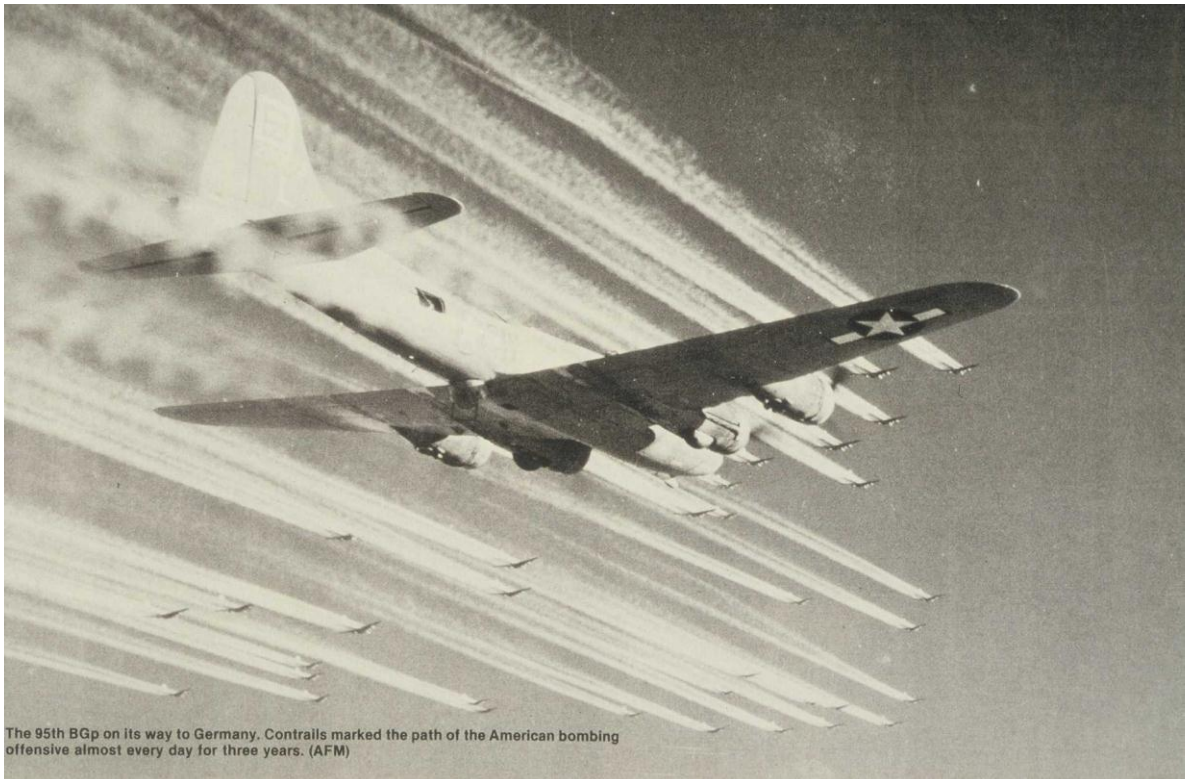
Of course, we will also need to be concerned with the infra-red signature of the target, which means shielding the hottest parts of the platform, such as the engine exhausts on an aircraft or the funnels of a ship, and minimising the temperature of exhaust gases. It is also possible to include additives in fuels so that emissions are centred in regions of the spectrum in which atmospheric transmission is low.

Similarly, the engine intake and exhaust are shaped to shield the rotating parts of the engine, to avoid Jet Engine Modulation (JEM) of radar echoes.

We should also consider the optical signature. Low reflectivity or mimetic paints may be used.

And equally, for ships, we will also be concerned with the acoustic signature, both active and passive.

Importance of contrail suppression

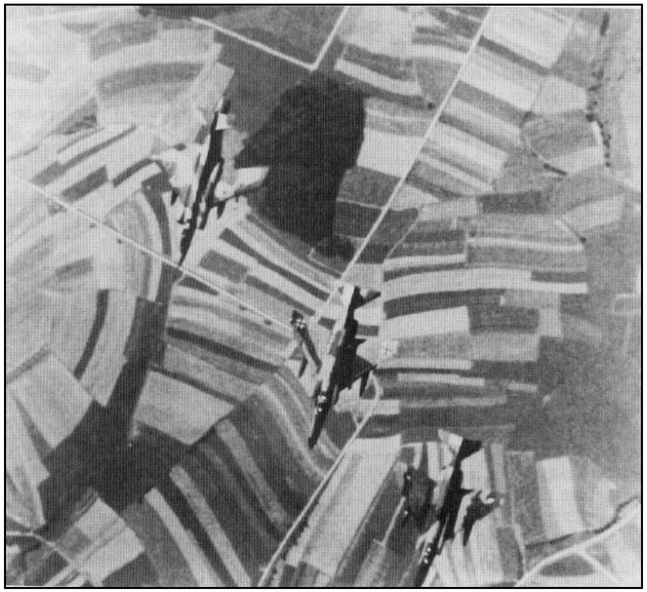


The 95th BGp on its way to Germany. Contrails marked the path of the American bombing offensive almost every day for three years. (AFM)

Contrails can be made invisible by injecting chloro-fluoro sulphonic acid into the engine exhaust gases. This reduces the size of the water droplets so that they scatter less light.

source : Barry Chambers, University of Sheffield

Optical camouflage



David H. Pollock, Countermeasure Systems, *The Infrared and Electro-Optical Systems Handbook*, Infrared Information Analysis Center and SPIE Optical Engineering Press, Volume 7, 1993

Sensor signatures

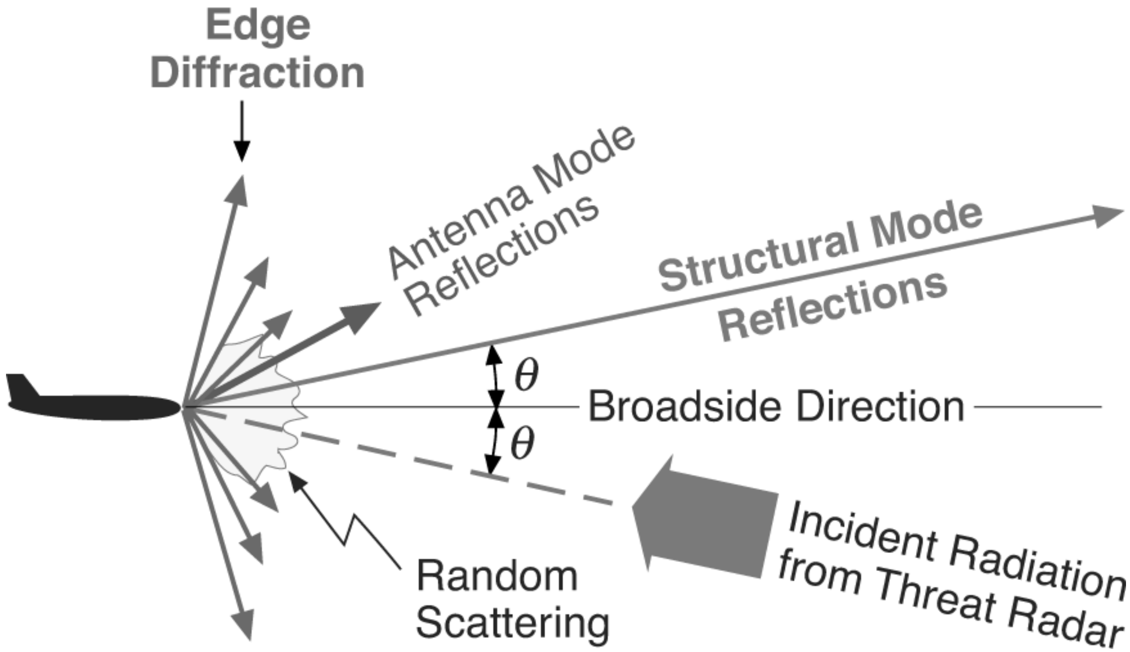
We need to be particularly concerned about the signatures of sensors – there’s no point in making the platform stealthy if the sensors become the dominant contribution to the overall signature.

The sensors can be mounted inboard, and only deployed when needed.

There is a particular problem with antennas (comms, radar, …). A mechanically-pointed tracking radar antenna will deliberately point directly at the object it is tracking. This can present a very large RCS to that object !

Antenna RCS is made up of two components: the *structural mode RCS*, made up of scattering from the antenna structure, and the *antenna mode RCS*.

Antenna signatures



- structural mode reflections
- antenna mode reflections
- edge diffraction
- random scattering

Antenna signatures

Structural RCS

- Antenna face: shape, orientation, edges
- Interface to vehicle
- Cavity and internal surfaces

Antenna mode RCS - i.e. reflections from inside antenna

- Radiating elements
- Isolation of major internal reflectors
- Reduction and cancellation of minor reflectors
- Uniformity across array

Grating lobes – i.e. above RF band spikes

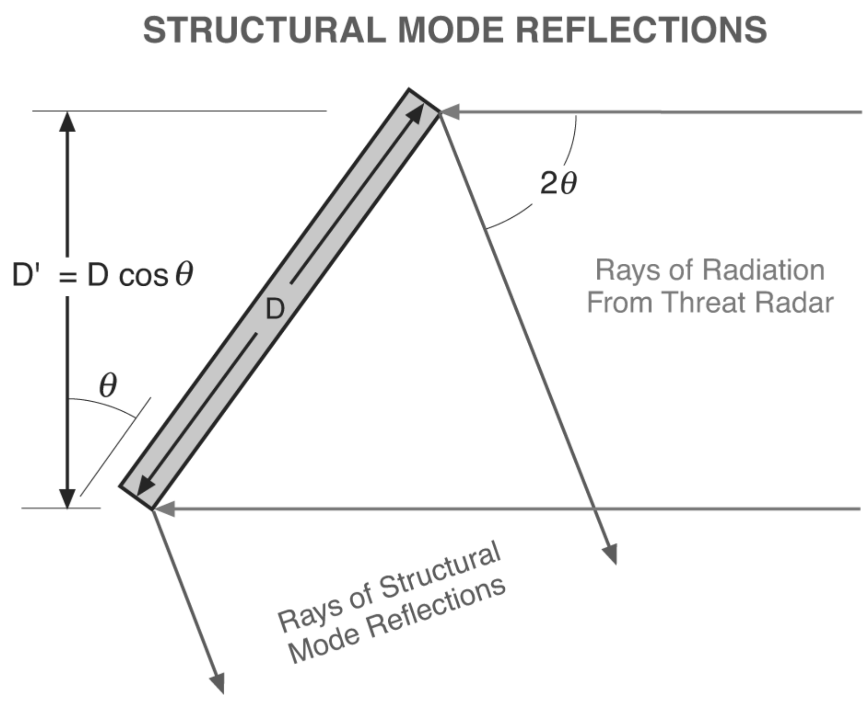
- Higher operating frequencies
- Filtering surfaces (radome or in antenna)

Lynch, D. Jr. *Introduction to RF Stealth*; SciTech/IEE, Raleigh NC, 2004.

Structural mode RCS

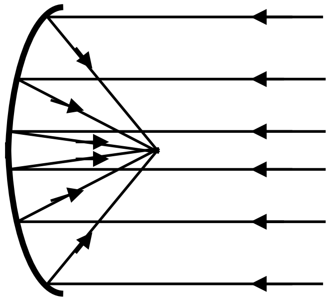
This can be defined as the RCS obtained when the antenna is terminated in a matched load (note that the various definitions in the literature are not totally consistent).

With an electronically-scanned antenna, mounted in a fixed position in an aircraft, the antenna ground plane can be permanently tilted so that the incident radiation will be harmlessly reflected in the same direction as the irreducible 'spike' in the pattern of reflections from the aircraft structure. The tilt reduces the antenna's effective aperture somewhat, reducing the gain and broadening the beam about the axis of tilt. But this is a small price to pay for the huge reduction is detectability that is achieved.



Antenna mode RCS

Assume an incident power density p W/m^2.
The power reaching the antenna feedpoint is then



$$p\frac{G\lambda^2}{4\pi}$$

The power reflected from the feedpoint is

$$|\rho|^2 \frac{pG\lambda^2}{4\pi}$$

where ρ is the voltage reflection coefficient. This is reradiated, so the antenna mode RCS in the direction of the main beam is

$$\sigma_A = \frac{G^2\lambda^2|\rho|^2}{4\pi}$$

But whilst ρ may be low within the operating band of the radar, outside that band it may be close to unity, so if we are not careful the antenna mode RCS can be very high !

Structural mode RCS

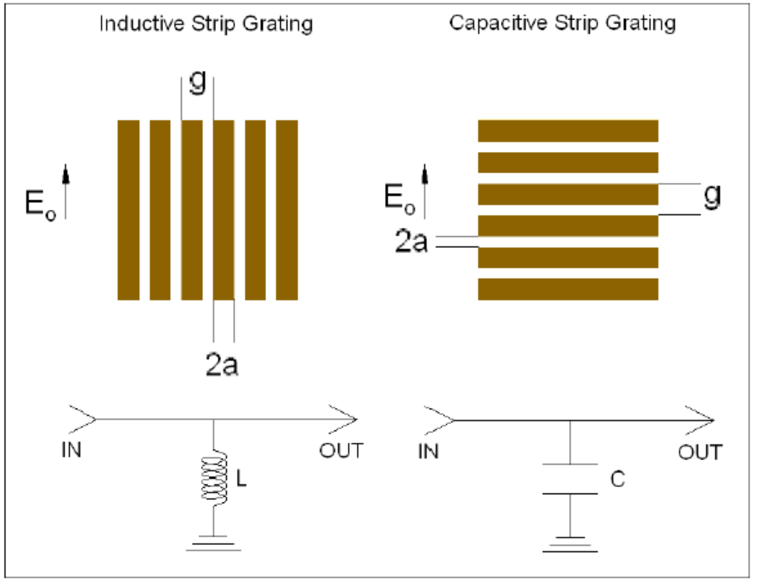
This can be defined as the RCS obtained when the antenna is terminated in a matched load (note that the various definitions in the literature are not totally consistent).

Consideration of the antenna mode and structural mode RCS leads to the concept of the *minimum scattering antenna*[1].

[1]Kahn, W.K. and Kurss, H., 'Minimum scattering antennas', *IEEE Trans. Antennas and Propagation*, Vol.AP-13, September 1965, pp671-675.

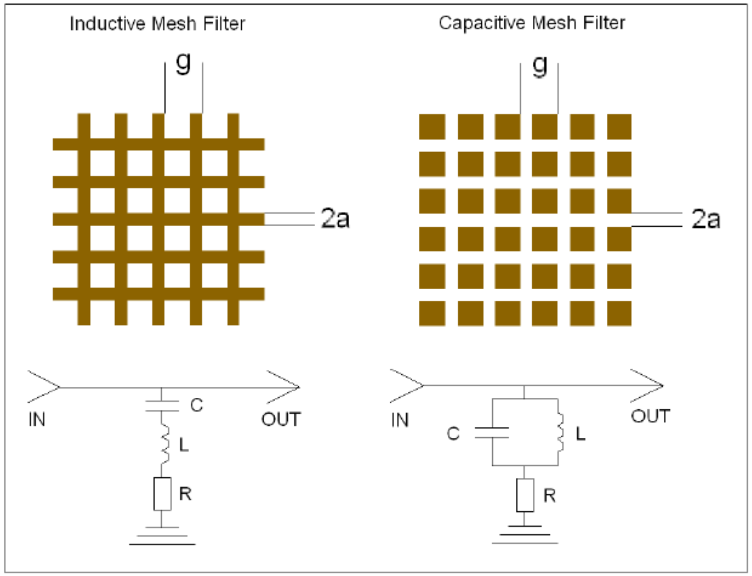
Frequency selective surfaces (FSSs)

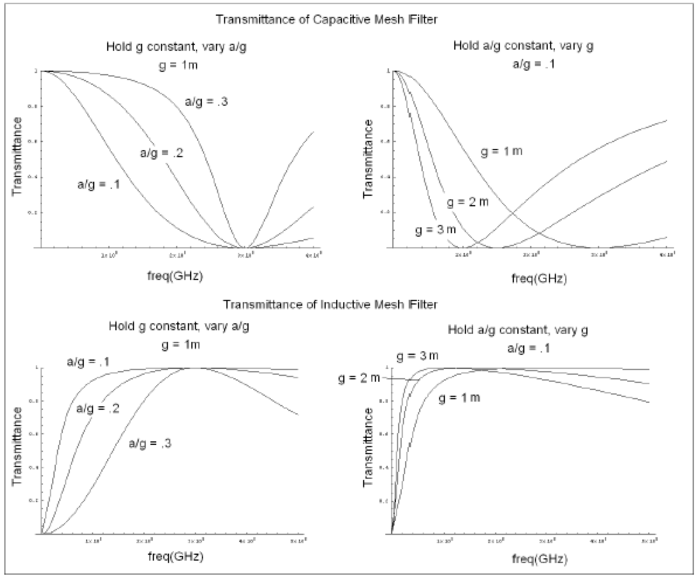
Printed periodic surfaces which can be designed to have specific transmission properties, in the same way as filter circuits



B. Hoobermann, *Everything you wanted to know about Frequency Selective Surfaces but were afraid to ask* http://calvin.phys.columbia.edu/group_web/filter_development/download/filter.pdf May 2005.

Frequency selective surfaces (FSSs)





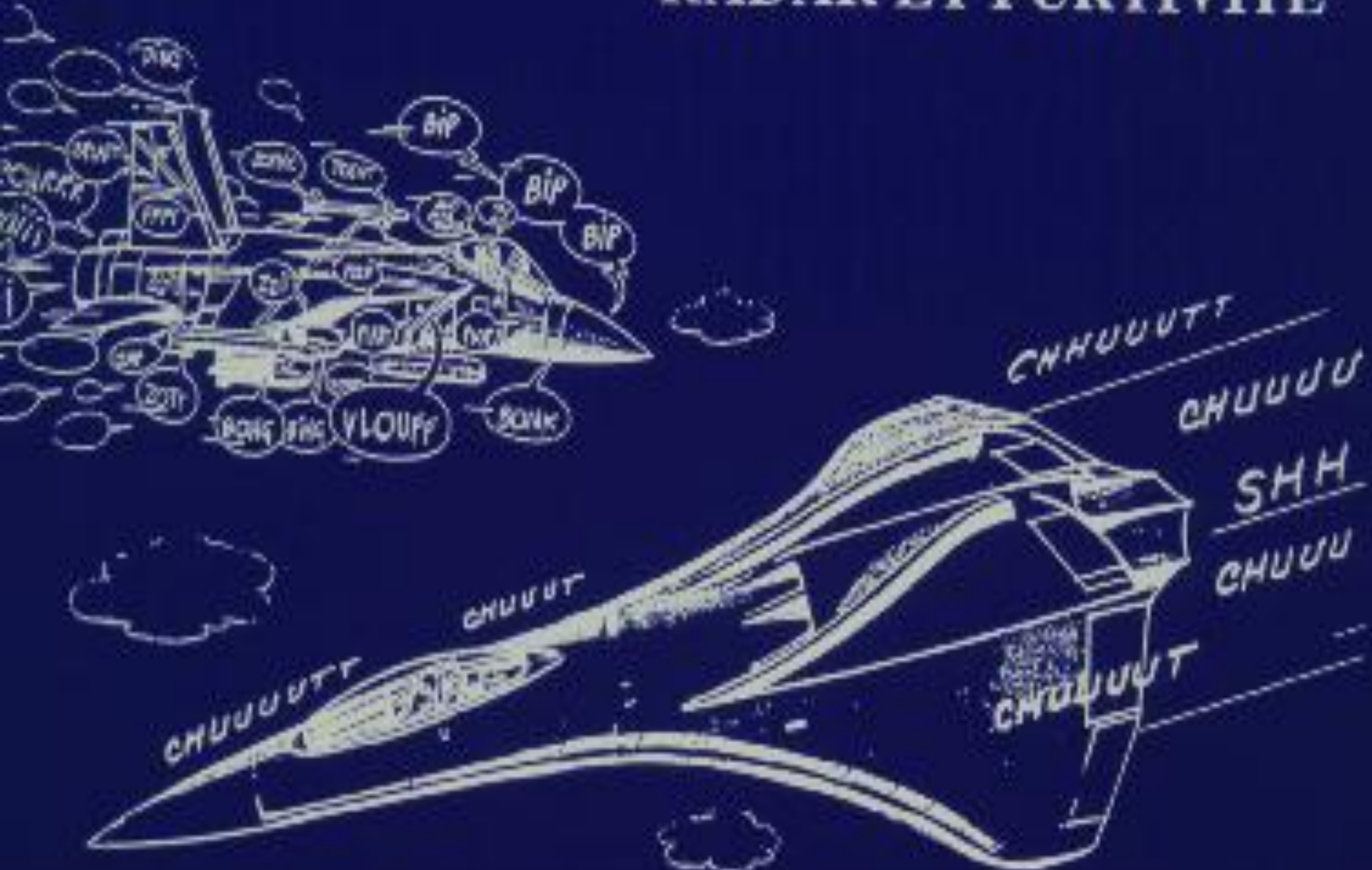
B. Hoobermann, *Everything you wanted to know about Frequency Selective Surfaces but were afraid to ask* http://calvin.phys.columbia.edu/group_web/filter_development/download/filter.pdf May 2005.

Target Radar Cross Sections

Small, single engine aircraft	1 m^2
Jumbo jet	100
Small open boat	0.02
Frigate (1000 tons)	5,000
Truck	200
Car	100
Bicycle	2
Person	1
Bird	0.01
Insect	10^{-5}

Adapted from M.I. Skolnik, *Introduction to Radar Systems*, 1962 (first edition).

RADAR ET FURTIVITE



CEA/DAM **CESTA**

QUELQUES AVIONS FURTIFS AMERICAINS:

Leurs formes:

La SER n'est plus liée à la taille de l'appareil, mais à l'effort de furtivité effectué.

B52:	100 m^2
Blackjack:	15 m^2
SR 71:	? m^2
B1-B:	0.75 m^2
B2:	0.1 m^2
F-117A:	0.025 m^2

Nous preparons l'avenir

Measurement of target signatures

This is extremely important, not only in the design and manufacture stage, but also in operation, since only a small amount of damage may increase the RCS dramatically.

Signatures are measured in special ranges. Scale models may be used in the design stage.

One important technique is Inverse Synthetic Aperture Radar (ISAR), in which the target is rotated in a known manner, and the motion used to obtain a high-resolution image of RCS, allowing ‘hot spots’ to be identified.

Stealth and detection range

We saw that the basic radar equation can be written in the form which shows the maximum detection range for a given target :

$$r_{\max} = \left[\frac{P_t G^2 \lambda^2 \sigma}{(4\pi)^3 \, kT_0 BF \; L \; S/N_{\min}} \right]^{1/4}$$

This means that a reduction in target RCS from (say) 100 m^2 to 0.01 m^2 (which on the face of it sounds like a huge reduction) reduces the detection range by a factor of 10 – which doesn't sound so much.

But the key point is that it reduces the time that a defensive system has to react.

Test your understanding

A ground-based air surveillance radar is able to detect an aircraft of RCS 10 m^2 at a maximum range of 200 km. At what range would it be able to detect a low-signature aircraft of RCS 0.01 m^2 ?

If the target is travelling at 1000 km/hr, by how much does this reduce the time that the defensive system has to react ?

Counterstealth

There are several radar techniques that may be used to attempt to restore the advantage that comes from making a target stealthy :

- Bistatic radar, since stealth techniques are aimed to reduce the monostatic RCS, and energy scattered in directions other than the monostatic direction may be intercepted by a bistatic receiver

- Low frequency (VHF or HF) radar, since the target signature is increased at frequencies at which the target dimensions are resonant, and RAM is less effective at low frequencies

- Ultra wideband (UWB) radar, which may exploit any target resonances, and because it is difficult to make a target stealthy over a very broad bandwidth

- Networked radars

- There are also several techniques that can be used to win performance in conventional radars, such as improved clutter models, reduced phase noise, improved tracking algorithms, and several ways of exploiting the flexibility of phased array radars to give longer dwell times.

Bistatic radar

Described in section 16 of this course.

- RCS reduction techniques aimed principally at minimising monostatic RCS; bistatic geometry can intercept energy scattered in other directions;
- Forward scatter geometry can give high RCS, even with truly stealthy targets;
- Passive receiver, immune to interception;
- Can utilise ‘illuminators of opportunity’

Low-frequency radar

Issues with resolution, both in azimuth (antenna size) and range (bandwidth).

Note also foliage penetration (FOPEN) properties of low frequencies – cf Swedish CARABAS SAR system (20 - 90 MHz) - plus others

FOPEN - detection of vehicles hidden in forests

High *fractional bandwidth* presents technology problems, especially with antenna design

and interference to and from broadcast transmissions may need special precautions

CARABAS I Experimental Demonstrator

CARABAS II/LORA

CARABAS parameters

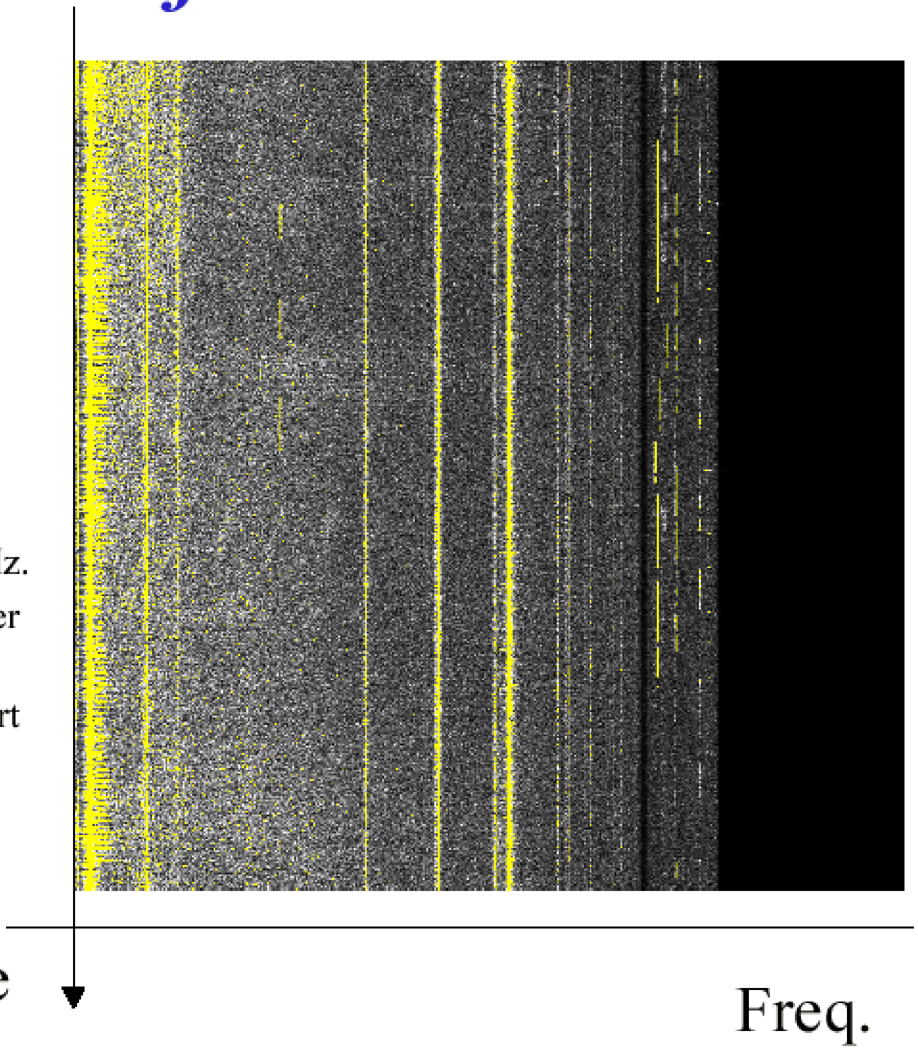
Aircraft	Rockwell Sabreliner
Nominal altitude	1,500 – 6,500 m
Nominal speed	100 m/s
Antenna	2 Wide Band Dipoles
Polarization	Horizontal
Frequency	20 – 90 MHz
Number of frequencies, n	≤ 57
Frequency stepping factor	1.25 MHz
Pulse length T_p	0.5 μs
Receiver bandwidth	2.5 MHz
Peak power	1 kW
System PRF, PRF_s	10 kHz
Effective PRF, PRF_e	10/2/n kHz
Intermediate Frequency	2.5 MHz
Digital Sampling Rate	10 MHz
Maximum Slant Range R_{max}	7.5 km
Number of Bits/Real Sample	12
Data Rate	80 MBits/s
Tape Recorder Capacity	107 MBits/s
Cassette Capacity	60 minutes

FOI

Sources of RFI

- Shortwave communication (20-30MHz)
- FM-radio (87.5-90MHz)
- low-VHF TV (47-68).

- radio short wave from around the world
- strong backscattering targets
- European personal seeker or cell phones
- television transmitter at 48 MHz
- Swedish television stations at 55 and 62 MHz.
- Communication frequencies using repeater techniques.
- CARABAS transmit notch for 75MHz airport radio beacon
- Hospital and police communication activity.



RFI Spectrum & Removal

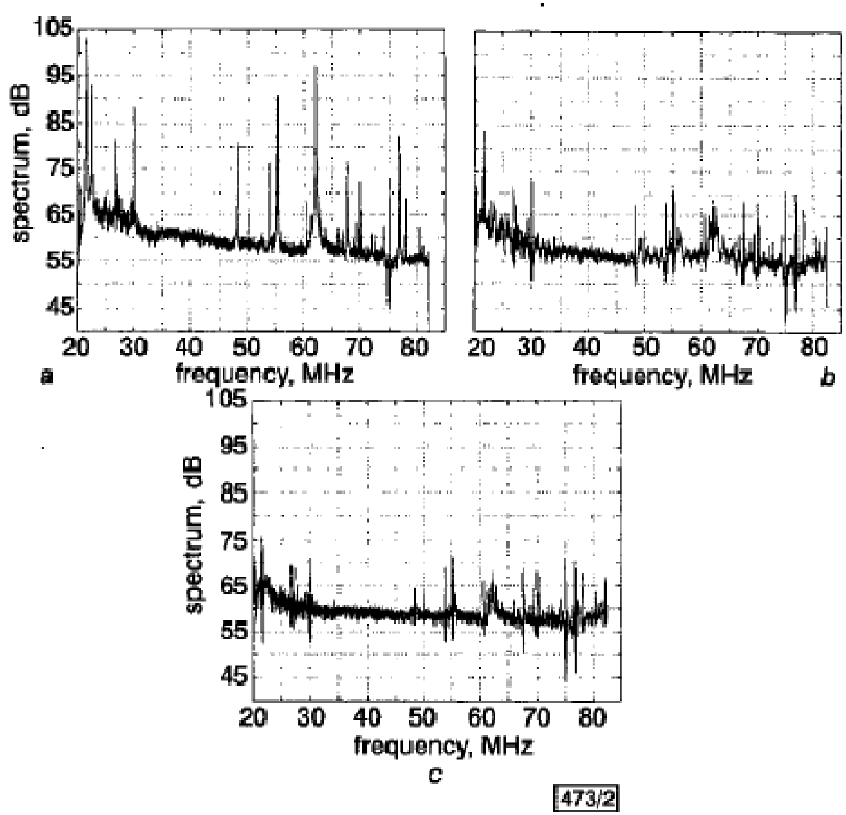


Fig. 2 *Range spectrum before and after filtering*

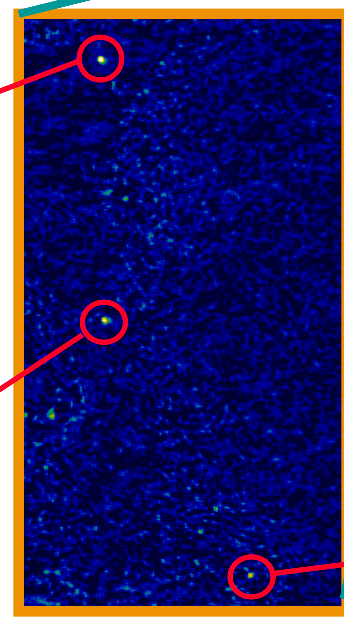
a Before RFI filtering
b Filtered using LMS-FD
c Filtered using LMS-SC

CARABAS VHF band SAR

Wide-area ground surveillance

Deny the enemy its sanctuaries whether in the open, or under concealment or camouflage

CARABAS-II
VHF-band SAR
20-90 MHz



Change detection

FOI

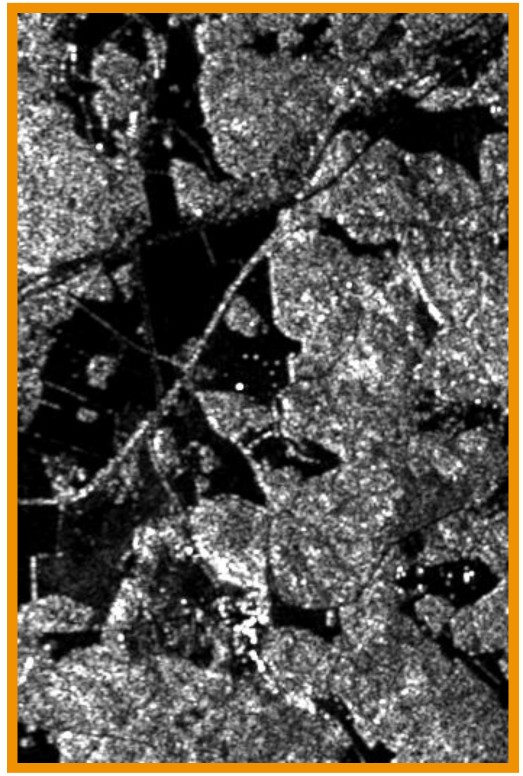
Radar backscattering vs. frequency

2.2 km

3.1 km

Radar illumination

X-band
German E-SAR
Res.: 2 m x 3 m

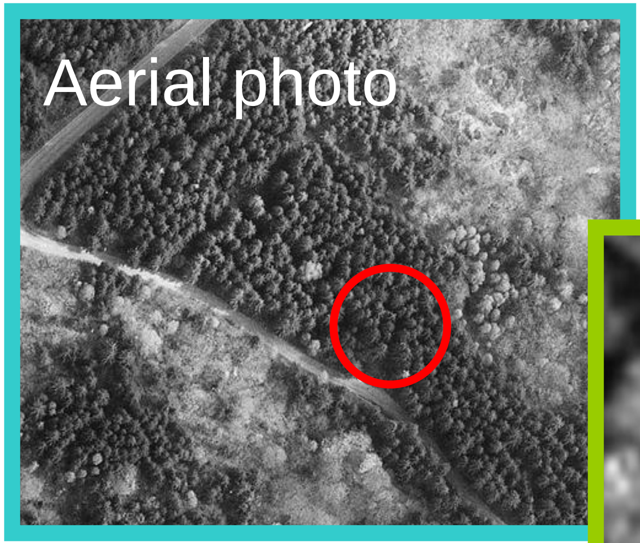


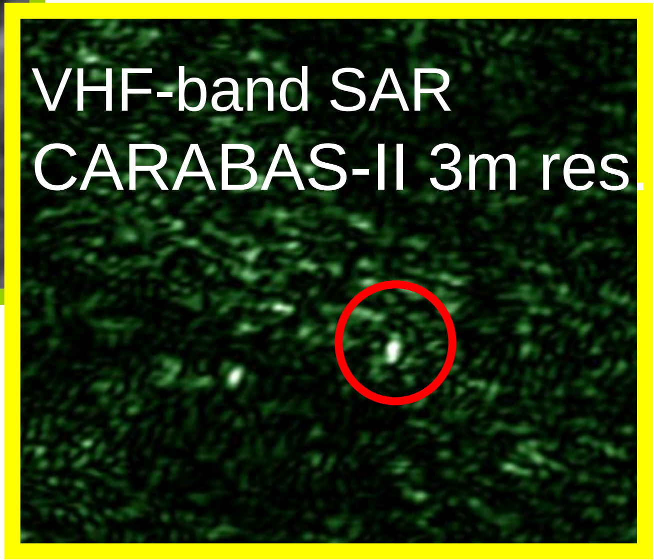
P-band
German E-SAR
Res.: 12 m x 10 m

VHF-band
Swedish CARABAS-II
Res.: 3 m x 3 m

FOI

Detection of Concealed Targets

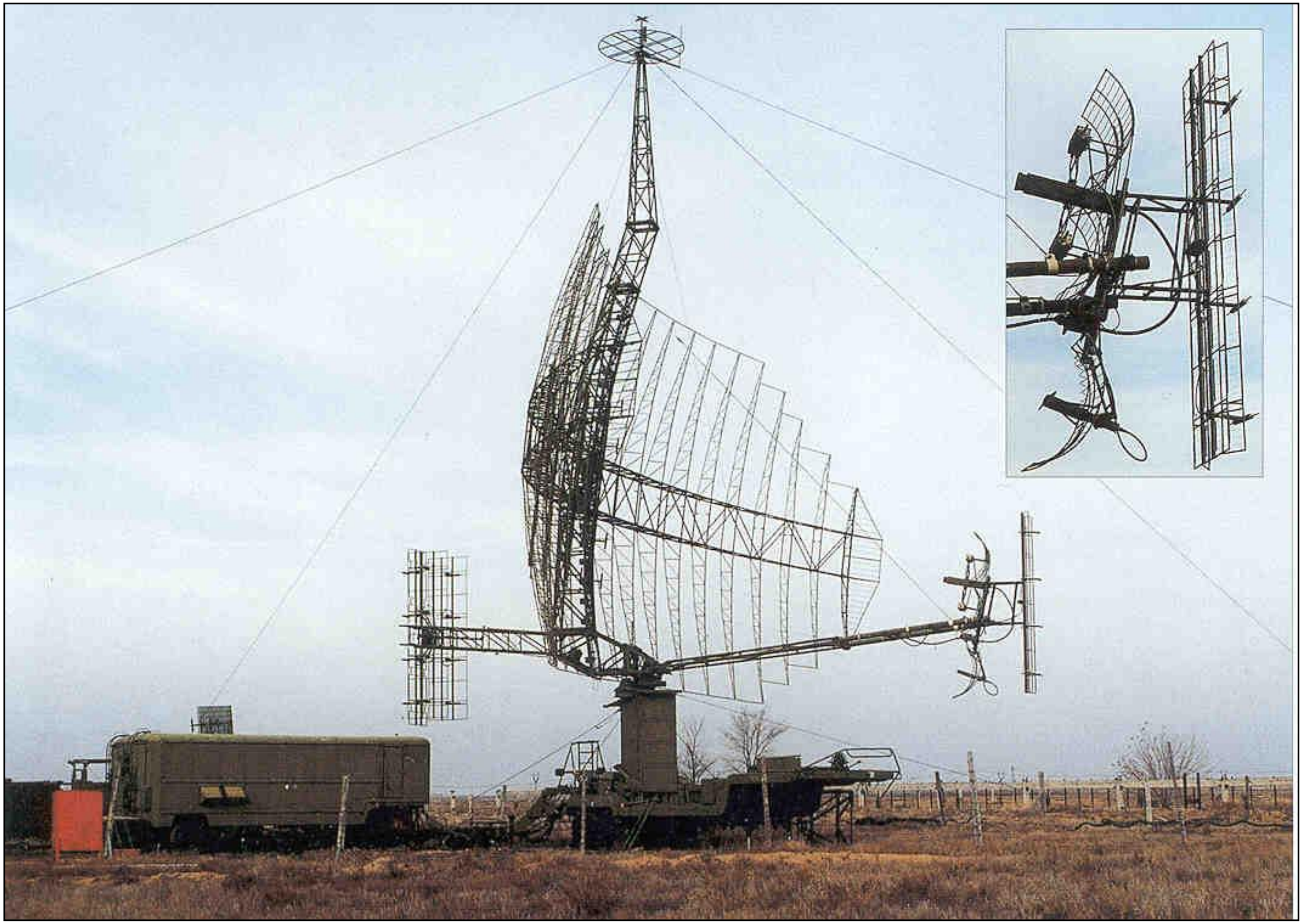




Attenuation is significantly reduced in VHF-band SAR, but forest clutter is still a problem.

FOI

TALL KING



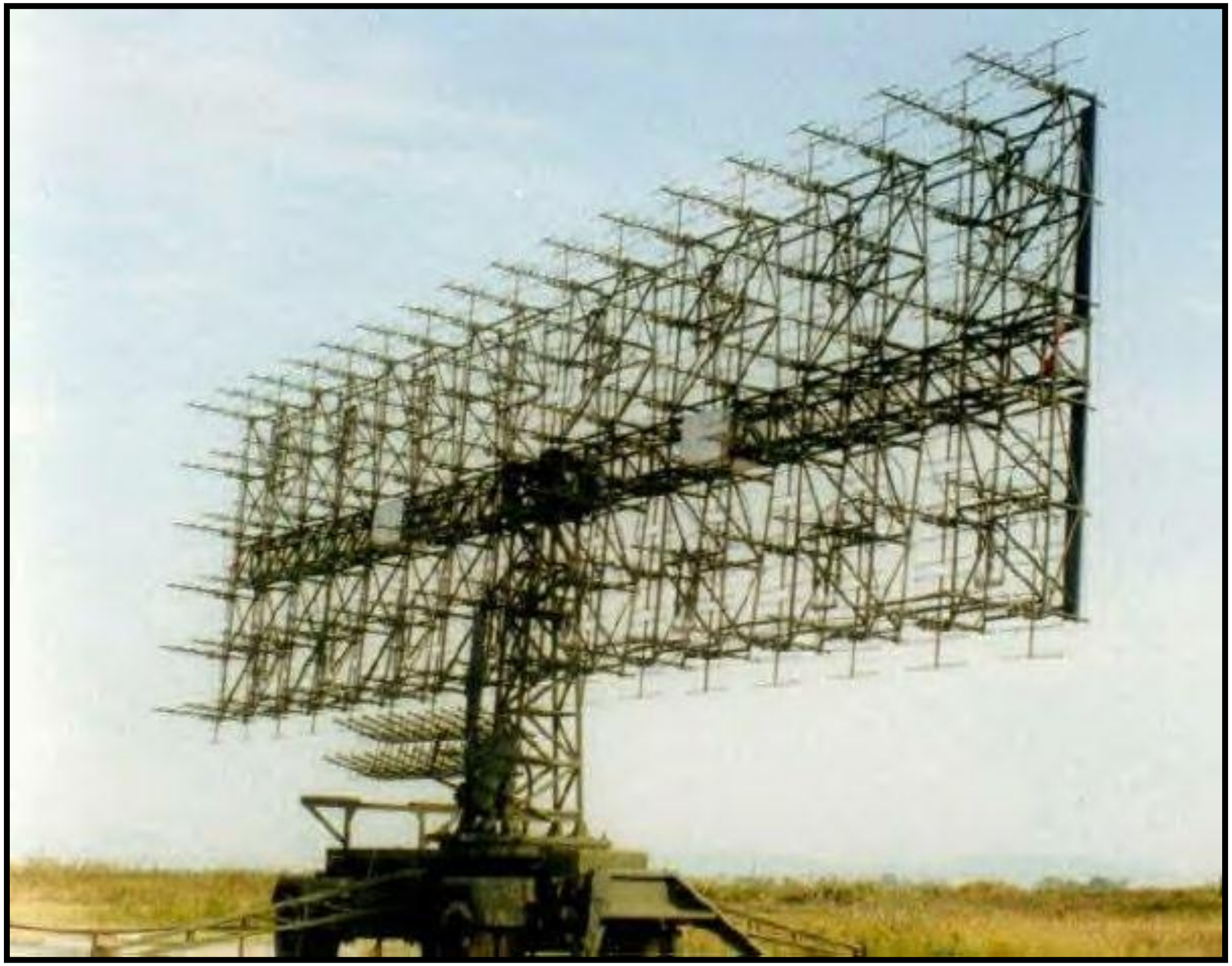
TALL KING estimated parameters (David Barton)

VHF band	λ = 1.8m	P_{av} = 10 kW
w = 32m	h = 12.5m	A_{r} = 240 m^2
θ_a = 3.5°	θ_e = 8.9°	t_s = 10s
T_s = 2000K	L_s = 100	σ = 1 m^2
ψ_s = 1.0 sr	$P_{av}A_r$ = 2400 Wm^2	R_m = 460 km

(exceeds typical 300 km requirement)

VHF radar

Another VHF radar: JY-27

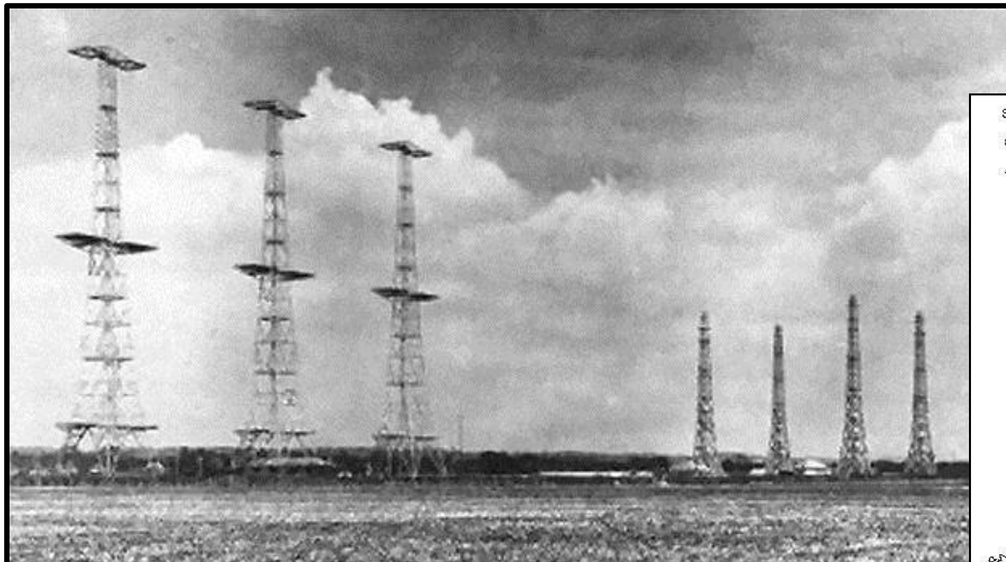


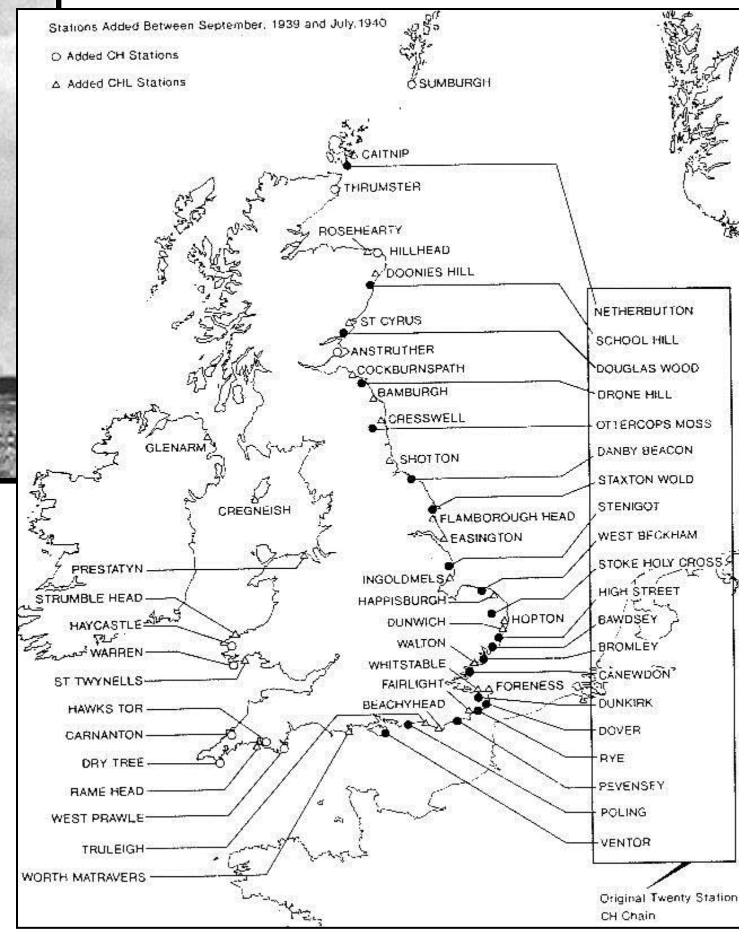
JY-27 estimated parameters (David Barton)

VHF band	$\lambda = 1.4$m	$P_{av} = 10$ kW
$W = 11$m	$h = 5$m	$A_{\mathrm{r}} = 55\ \mathrm{m}^2$
$\theta_a = 6°$	$\theta_e = 13°$	$t_s = 10$s
$T_s = 1000$K	$L_s = 100$	$\sigma = 1\ \mathrm{m}^2$
$\psi_s = 1.5$ sr	$P_{av}A_r = 550\ \mathrm{Wm}^2$	$R_m = 340$ km

(exceeds typical 300 km requirement)

HF radar: CHAIN HOME



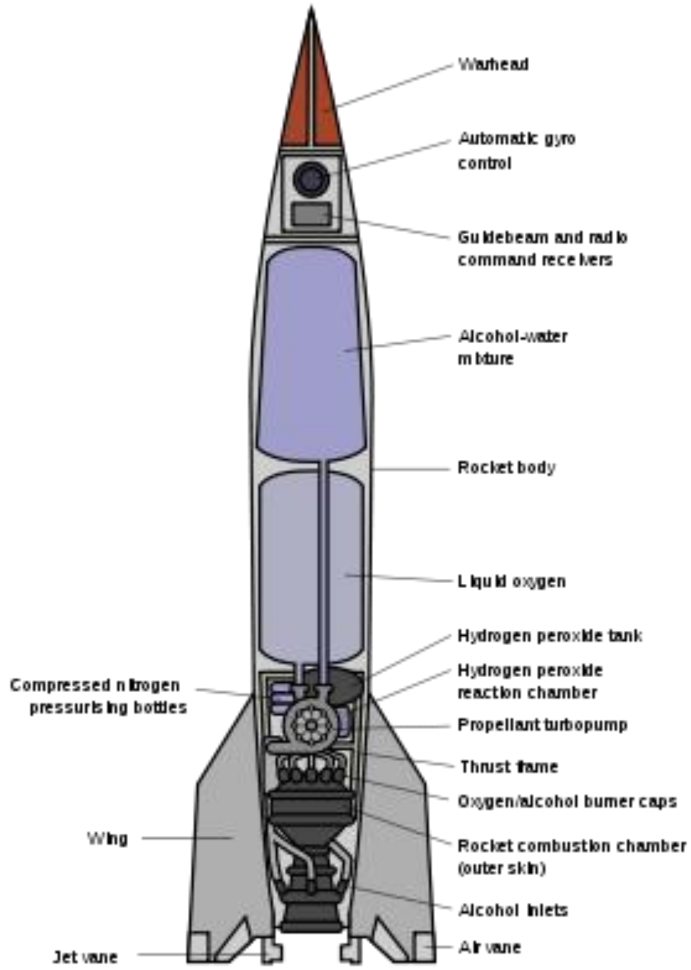


Neale, B.T., ‘CH – the First Operational Radar’, *GEC Journal of Research*, Vol. 3 No.2 pp73-83, 1985.

V-2 ROCKETS

- The V-2 rocket was about 13.6 m in length and 1.65 m maximum diameter. Its fuel was a 75% ethanol/water mixture with liquid oxygen as oxidant
- It carried a warhead of about 1 ton of explosive
- Developed over several years at Peenemünde
- A key figure in the project was Wernher von Braun, who after the War emigrated to the USA where he helped lay the foundations of the US Space Program
- First successful test flight took place on 3 October 1943

V-2 ROCKETS



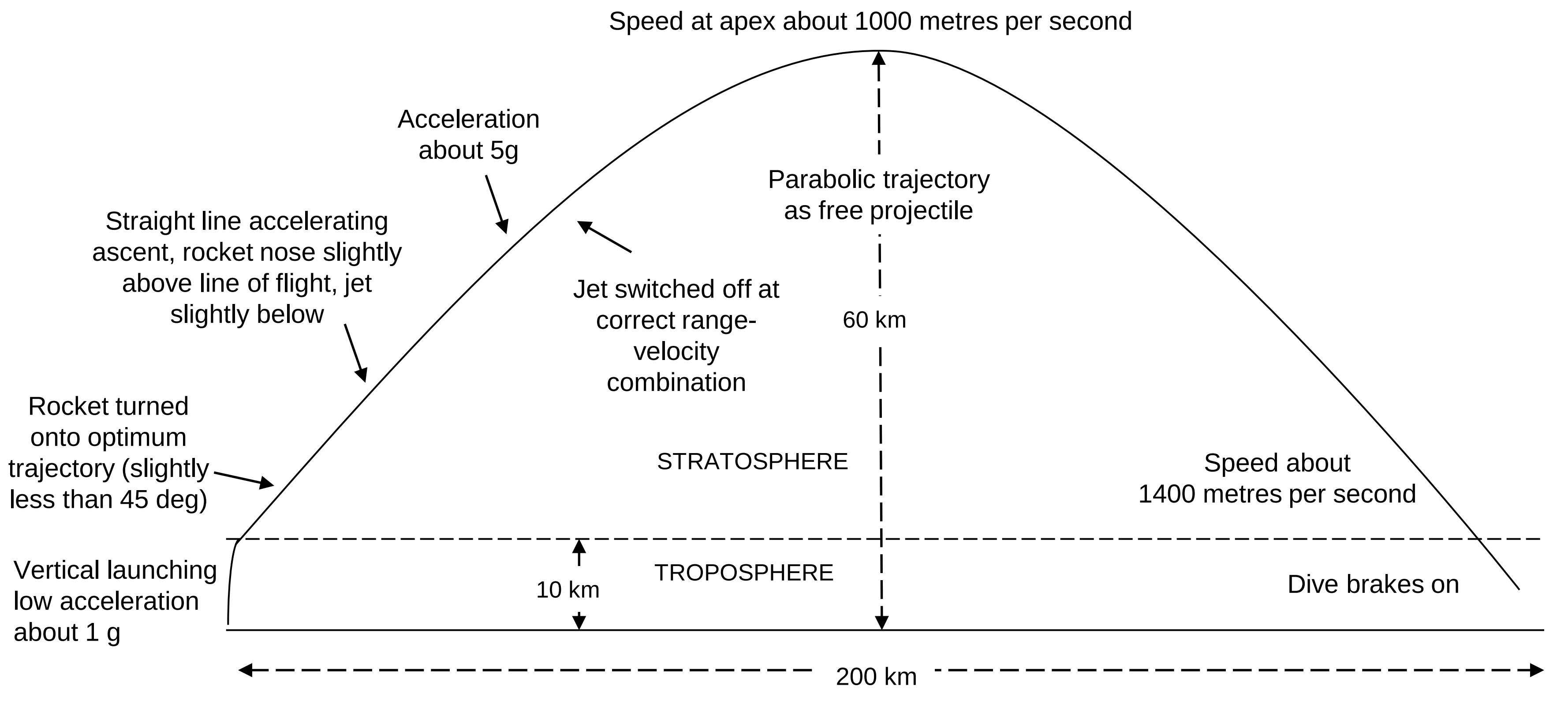
Warhead
Automatic gyro control
Guidebeam and radio command receivers
Alcohol-water mixture
Rocket body
Liquid oxygen
Hydrogen peroxide tank
Hydrogen peroxide reaction chamber
Compressed nitrogen pressurising bottles
Propellant turbopump
Thrust frame
Oxygen/alcohol burner caps
Wing
Rocket combustion chamber (outer skin)
Alcohol inlets
Jet vane
Air vane

North Sea
NETHERLANDS
Ommen
Archem
Burgsteinfurt
Rijs
Norwich
Dalfsen
Hellendoom
Wassenaar
The Hague
Hoek van Holland
Darfield
Ipswich
Heek
London
Serooskerke
Middleburg
Haaksbergen
Kleve
Antwerp
Nikverdal
Maastricht
Lille
Liége
GERMANY
English Channel
Headquarters
V-2 launch Sites
Targeted Cities
Distance: 247km
Altitude: 80km

V-2 ROCKETS

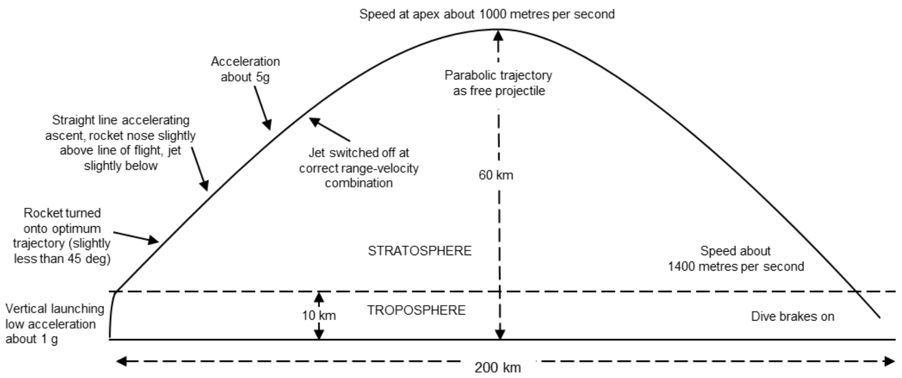
- By April 1943 British Intelligence had found out about the work at Peenemünde
- The CROSSBOW Committee was set up, chaired by Sir Robert Watson-Watt. The threat was given the codename BIG BEN
- On 13 June 1943 a V-2 rocket on a test flight Peenemünde crashed in Sweden. The wreckage was given to the British in exchange for a number of Spitfire aircraft
- The Royal Air Force mounted a substantial bombing raid on Peenemünde on 18 August 1943

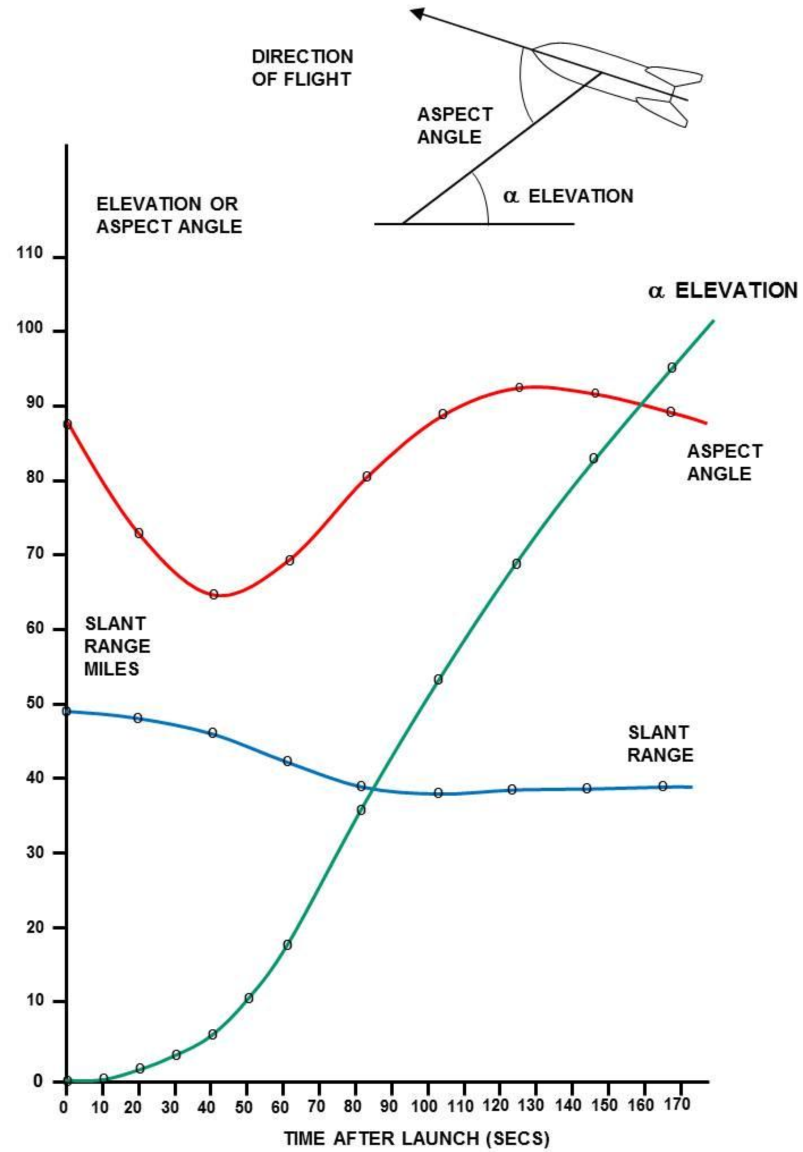
V-2 trajectory



R.V. Jones, *Most Secret War*, Fig. 31b, p456.

Visibility of BIG BEN to radar

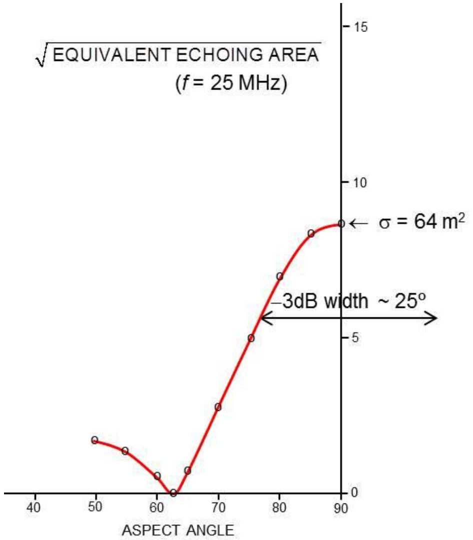




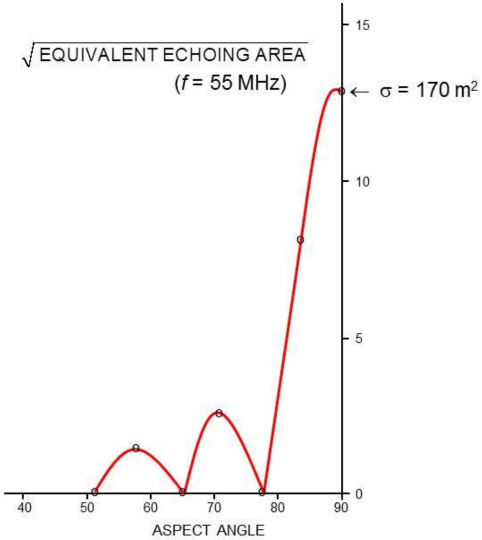
Visibility of BIG BEN to Radar, TRE IIE/193/6/2, (AIR 20/10941), 27 August 1944.

Visibility of BIG BEN to radar

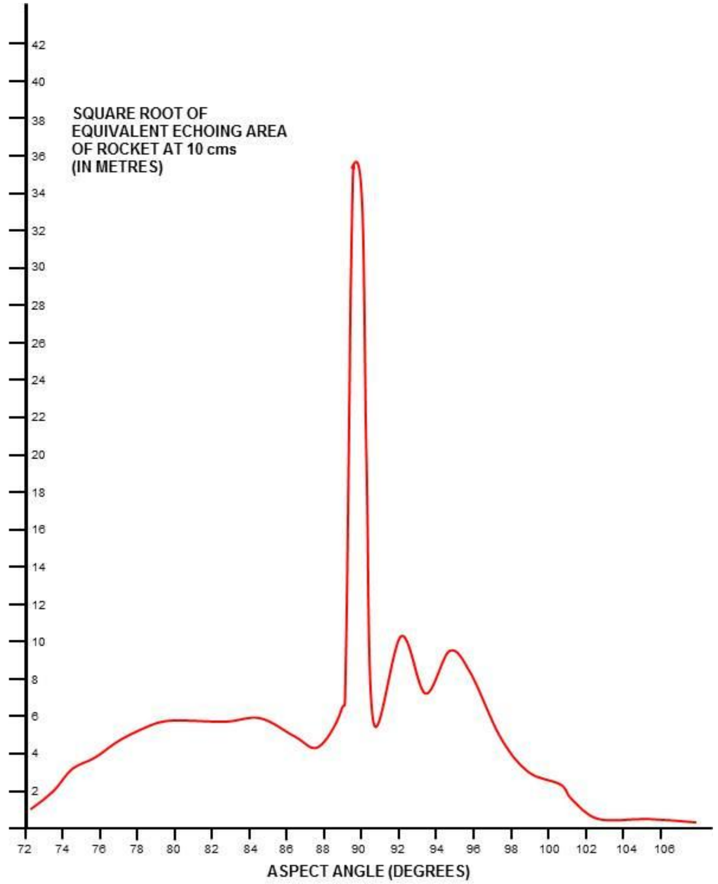
25 MHz



55 MHz



3 GHz



Visibility of BIG BEN to Radar, TRE IIE/193/6/2, (AIR 20/10941), 27 August 1944.

V-2 rockets

- The first V-2s were launched at London on 7 September 1944, by which time the British clearly had a good idea of what to expect.

- Unlike the V-1s (whose pulse-jet engine gave a characteristic sound which led to its ‘buzz-bomb’ nickname) there was no indication of their approach: the first sign was the explosion of the warhead, followed immediately by the boom due to the supersonic velocity.

- By 7 April 1945 1,190 V-2s had successfully been launched against London. Slightly more than this number were launched from Germany towards targets on the European mainland, notably the Belgian city of Antwerp which was an important port for Allied supply routes.

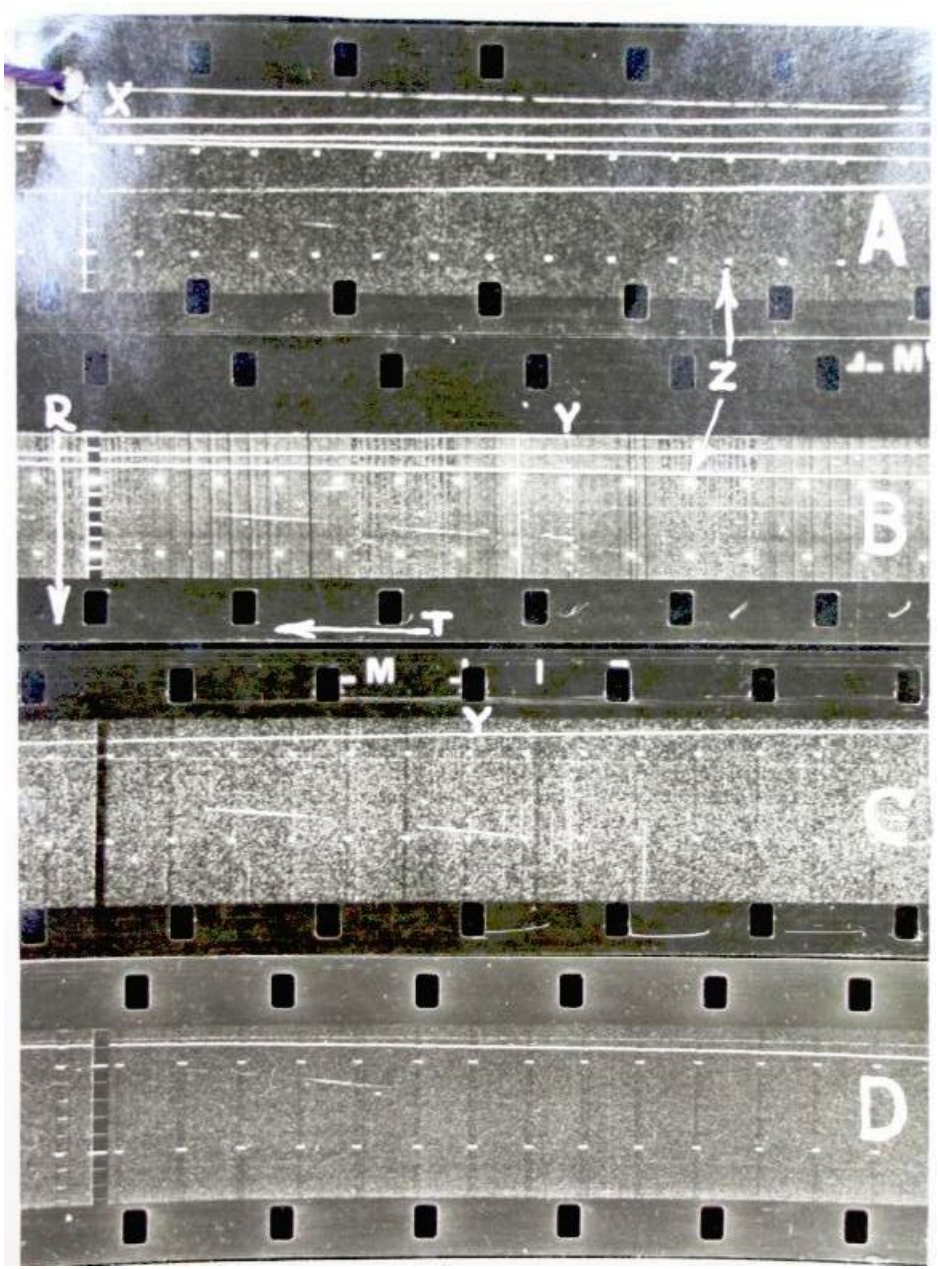
Oswald and Willie

- Special techniques were necessary to maximise the probability of detection, presenting the information to the radar operators in the most suitable way on the CRT display and recording the data, with timing marks, photographically.

When the V-2 rockets came along, special equipment was installed in the R block. Known as ‘Oswald’, the screen showed a faint but distinctive thread-like track when a V-2 scorched through the atmosphere. The operator then yelled ‘Big Ben at Bawdsey’ down the line to the Filter Room … The screen of ‘Oswald’ had to be watched very intently. The tracks were so small and appeared so briefly, that they could be missed altogether if the operator blinked.

OSWALD

‘Oswald’ photographic record of detection of a single V-2 launch by CH radars at High Street (A), Bawdsey (B), Great Bromley (C) and Swingate (D). In each case the data is presented in terms of range (R) vertically downwards and time from launch (T) horizontally from right to left. Also visible are timing markers at intervals of 6 seconds (Z), 2 minutes (Y) and 30 minutes (X). The long streaks showing only slow variation of range with time are aircraft echoes.



Ultra Wideband Radar

Can be defined as a radar with a fractional bandwidth greater than 0.25 (DARPA).

UWB radar systems are divided essentially into two types.

The first are so-called impulse radars, which transmit a very narrow high-power impulse, and process the received echo in the time domain. The hardware involved in such radars tends to be rather specialised, especially for anything other than short-range applications, calling for techniques to generate high peak power impulses, and components with very high instantaneous bandwidths. The bandwidth of the impulse, though, extends almost down to dc. There is considerable work in several countries going on in high-power short-pulse electromagnetics, and it is arguably a subject in its own right.

The second type uses pulse compression techniques to obtain the high range resolution, typically with wide-bandwidth chirp or step-CW waveforms. The peak power requirements are correspondingly lower, and the hardware doesn’t necessarily have the same requirement for instantaneous broad bandwidth.

Note also ‘spectral interpolation’ techniques, in which data from two or more discontinuous bands can be combined together.

Ultra Wideband Radar

Ultra-wideband radar gives very high range resolution, which can be useful in target classification, and is potentially useful as a counter-stealth technique because it is difficult to make a target stealthy over the whole of the radar bandwidth.

It is also important to state that fundamentally, for the same waveform spectral content, and as long as there are no non-linear effects, there is no difference in target signature between the impulse approach and the pulse compression approach.

Impulse Radar

In the late 1980s, a study was commissioned by the Defense Advanced Research Projects Agency (DARPA) in the USA, into Ultra-Wideband Technology, since it had been suggested that such technology might offer a counter-stealth capability. The panel undertaking the study included many well-known names from the US radar research community.

The report was published in July 1990 [1], and concluded, amongst other things, that impulse radar '… is not inherently anti-stealth', '… has no special LPI characteristics', and '… does not offer a major new military capability, nor correspondingly does it present the threat of a serious technology surprise'.

The report caused concern in some quarters, owing to its impact on emerging stealth technologies, and an investigation of the panel and its activities was undertaken. This investigation concluded that '… the panel's report was credible and the panel balanced'. An account of the panel's work and of the investigation was published in the IEEE AESS Magazine [2].

[1] 'Assessment of Ultra-Wideband (UWB) Technology', DTIC No. ADB146160, 13 July 1990. The Executive Summary of the report was published in *IEEE AESS Magazine*, pp45 – 49, November 1990.

[2] Fowler, C.A., 'The UWB (impulse radar) caper *or* "punishment of the innocent"', *IEEE AESS Magazine*, pp3 – 5, December 1992.

Summary

- The radar signature of a target may be reduced by shaping and/or by covering the surface with absorbing material

- The reduction in maximum detection range is dictated by the $1/R^4$ factor in the radar equation – but it's the reduction in reaction time of the defensive system that is most significant.

- The radar signature of sensors is potentially dominant.

- It's important to consider all aspects of the signature – radar, IR, optical, acoustic ….

Further Reading

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