Radar + Stealth

Invented around WW II - uses EM radiation to discover planes, boats, etc.

Frequency of operation

Radar tries to make the target into a reflecting antenna.

So \( \lambda \sim \frac{L}{f} \),

- size of object
- wave length

For planes:

\[ L \sim 10m \]

\[ f = \frac{c}{L} \sim 30 \text{ MHz} \]

Good guess. Except: too sensitive.

Move modern radar: looks for smaller
\[ f \sim 16 \text{Hz} : \]
\[ \lambda = \frac{c}{f} \]
\[ = \frac{3 \times 10^8}{10^3 \text{Hz}} = 0.3 \text{m} \]

From Wikipedia:

### Radar frequency bands

<table>
<thead>
<tr>
<th>Band</th>
<th>Frequency range</th>
<th>Wavelength range</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>HF</td>
<td>3–30 MHz</td>
<td>10–100 m</td>
<td>Coastal radar systems, over-the-horizon radar (OTH) radars; 'high frequency'</td>
</tr>
<tr>
<td>P</td>
<td>&lt; 300 MHz</td>
<td>1 m+</td>
<td>'P' for 'previous', applied retrospectively to early radar systems</td>
</tr>
<tr>
<td>VHF</td>
<td>30–300 MHz</td>
<td>1–10 m</td>
<td>Very long range, ground penetrating; 'very high frequency'</td>
</tr>
<tr>
<td>UHF</td>
<td>300–1000 MHz</td>
<td>0.3–1 m</td>
<td>Very long range (e.g. ballistic missile early warning), ground penetrating, foliage penetrating; 'ultra high frequency'</td>
</tr>
<tr>
<td>L</td>
<td>1–2 GHz</td>
<td>15–30 cm</td>
<td>Long range air traffic control and surveillance; 'L' for 'long'</td>
</tr>
<tr>
<td>S</td>
<td>2–4 GHz</td>
<td>7.5–15 cm</td>
<td>Moderate range surveillance, Terminal air traffic control long-range weather, marine radar; 'S' for 'short'</td>
</tr>
<tr>
<td>C</td>
<td>4–8 GHz</td>
<td>3.75–7.5 cm</td>
<td>Satellite transponders; a compromise (hence 'C') between X and S bands; weather; long range tracking</td>
</tr>
<tr>
<td>X</td>
<td>8–12 GHz</td>
<td>2.5–3.75 cm</td>
<td>Missile guidance, marine radar, weather, medium resolution mapping and ground surveillance; in the USA the narrow range 10.525 GHz ±25 MHz is used for airport radar; short range tracking. Named X band because the frequency was a secret during WW2.</td>
</tr>
<tr>
<td>K_u</td>
<td>12–16 GHz</td>
<td>1.67–2.5 cm</td>
<td>High-resolution, also used for satellite transponders, frequency under K band (hence 'u')</td>
</tr>
<tr>
<td>K</td>
<td>18–24 GHz</td>
<td>1.11–1.67 cm</td>
<td>From German kurz meaning 'short'; limited use due to absorption by water vapour; so K_u and K_s were used instead for surveillance. K-band is used for detecting clouds by meteorologists, and by police for detecting speeding motorists. K-band radar guns operate at 24.150 ± 0.100 GHz.</td>
</tr>
<tr>
<td>K_s</td>
<td>24–40 GHz</td>
<td>0.75–1.11 cm</td>
<td>Mapping short range, airport surveillance; frequency just above K band (hence 'a'). Photo radar, used to trigger cameras which take pictures of license plates of cars running red lights, operates at 34.300 ± 0.100 GHz.</td>
</tr>
<tr>
<td>mm</td>
<td>40–300 GHz</td>
<td>7.5 mm – 1 mm</td>
<td>Millimetre band, subdivided as below. The frequency ranges depend on waveguide size. Multiple letters are assigned to these bands by different groups. These are from Baytron, a now defunct company that made test equipment.</td>
</tr>
<tr>
<td>V</td>
<td>40–75 GHz</td>
<td>4.0–7.5 mm</td>
<td>Very strongly absorbed by atmospheric oxygen, which resonates at 60 GHz.</td>
</tr>
<tr>
<td>W</td>
<td>75–110 GHz</td>
<td>2.7–4.0 mm</td>
<td>Used as a visual sensor for experimental autonomous vehicles, high-resolution meteorological observation, and imaging.</td>
</tr>
<tr>
<td>UWB</td>
<td>1.6–10.5 GHz</td>
<td>18.75 cm – 2.8 cm</td>
<td>Used for through-the-wall radar and imaging systems.</td>
</tr>
</tbody>
</table>
Stealth

* Control of reflecting surfaces.

not good.

better...

lots of reflection to original radar.

boring. And makes for ugly looking planes:

* plastic planes:

use carbon composites.

It should be like that...

First "steathy" passenger plane.
* Radar Absorbing Materials *

"Iron ball paint" plays a dominant role. Details are scarce.
Can we figure it out?

Metal spheres:

Assume: $r \ll \lambda$
Only magnetic induction important.

Eddy currents dissipate wave energy.

$\uparrow^\uparrow$ $B \cos \omega t$

$EMF \sim \frac{d\Phi}{dt} \sim \pi r^2 \omega B$

Current response:

$I = \frac{EMF}{2}$
2 - Impedance:

1. Inductance:
   Ampere's Law cheat:
   \[ B \cdot dl = \mu_0 I \]
   So:
   \[ B \cdot r = \frac{I}{\mu_0} \]
   and:
   \[ V = \frac{dB}{dt} \cdot \pi r^2 = \mu_0 \pi r \cdot \frac{I}{\mu_0} = L \cdot \frac{I}{\mu_0} \]
   \[ L = \mu_0 \cdot \pi \cdot r \]

2. Resistance:
   \[ R = \frac{\frac{BL}{\mu_0} - \frac{\mu_0 (2\pi r)}{\mu_0}}{A} \approx 2 \frac{L}{r} \]

   \[ I = \frac{\omega B \pi r^2}{\omega L + R} \approx \frac{\omega B \pi r^2}{\omega \mu_0 \pi r + \frac{2\pi}{r}} \]

   \[ |E|^2 = \frac{1}{2} \left( \frac{B^2 \pi r^2}{\mu_0} \right) \cdot \frac{\omega^2 \pi r^2}{\omega^2 + \frac{4\pi^2}{\mu_0 r^2}} \]

   AC average.
\[ I^2 R = \frac{B^2}{\tau} \cdot \frac{29}{r^2} \cdot \frac{1}{\pi \omega_0^2} \cdot \frac{4.7^2}{\pi r^4 \omega_0^2} \cdot \frac{1}{2} \]

or even better:

\[ = \frac{B^2}{\tau_0} \cdot \pi r^2 \cdot C \cdot \left( \frac{29}{\pi \omega_0} \right) \cdot \frac{1}{1 + \frac{4.7^2}{\pi r^4 \omega_0^2}} \]

This, for one, explains the F-117 interception in Serbia:

**1999 F-117A shootdown**

Unknown to NATO, Yugoslav air defenses operators had found they could detect F-117s with their "obsolete" Soviet radars after some modifications. [2] In 2005, Colonel Zoltan Dani confirmed in an interview suggested that those modifications involved using long wavelengths, allowing them to detect the aircraft when the wheel well or bomb bay doors were open. [3] In addition, the Serbs had also intercepted and deciphered some NATO communications, and thus were able to deploy their anti-air batteries at positions best suited to intercept NATO planes. [3]

The lower the frequency \( \omega \), the worse is the absorption...
Best r?

Imagine layering:

$$
\alpha = \text{Fraction of power absorbed} \approx \frac{1}{2} \left( \frac{d}{2r} \right) \left( \frac{2g}{r} \right) \left( \frac{1}{\pi f_0 c} \right) \frac{1}{1 + \frac{4r^2}{\pi^2 f_0^2 c^2}}
$$

number of "layers"

$$
\alpha = d \cdot \frac{2}{\pi} \cdot \frac{g}{f_0 c} \cdot \frac{1}{r^2 + \frac{W^4}{r^2}}
$$

with:

$$
W \approx \sqrt{\frac{2g}{\pi f_0 c}} \sim \sqrt{\frac{2 \cdot 10^{-8} \text{ m}}{3 \cdot 10^{-6} \cdot 2\pi \cdot 10^3 \text{ Hz}}} \sim 10^{-6} \text{ m}
$$

Optimum: \( r \sim W \)
This gives: \( d = 4 \text{ mm} \)

\[
\alpha \approx 10^{-3} \cdot \frac{10^{-8}}{2 \cdot m} \cdot \frac{1}{\pi \cdot 3.775 \cdot (10^{-6} \text{ m})^2} = 10^{-2} = 1\%.
\]

hmm... not much...

WAIT! Did they say iron?

Iron is ferromagnetic:

(18000
\[ \mu_{\text{rel}} = \begin{cases} 
18000 & \text{annealed} \\
5000 & \text{not annealed}
\end{cases} \]

Wikipedia on permeability)

\[ \uparrow \quad \text{Bout}. \]
For AC, at \( f = 16 \text{MHz} \): Seems

\[ \phi_{\text{rel}} \approx 10^{-100} \]

Take \( \phi_{\text{rel}} \approx 30 \).

What should we change?

\[ \text{EMF} \rightarrow \phi_{\text{rel}} \cdot B \cdot C \cdot \pi r^2 \]

Also:

\[ L \rightarrow \phi_{\text{rel}} \cdot \pi r^4 \]

Together this modifies \( W \):

\[ W \rightarrow \sqrt{\frac{2 \cdot \phi_{\text{rel}}}{\pi \cdot C \cdot W}} \]

And the result becomes:

\[ \alpha \rightarrow \phi_{\text{rel}} \alpha = 30\% \]

So \( W \): thicker layer (\( \alpha_{\\text{mm}} \))
We can eliminate all radiation.

Mass of extra material

Is it feasible?

\[ M = 9.5 \text{ m}^2 \times 0.006 \text{ m} = 1500 \text{ kg} \]

\[ \approx 5 \times 10^3 \text{ kg/m}^3 \text{ guess...} \]

Feasible although heavy. Plane mass \( \approx 15 \text{ tons} \) anyway.

Also: maybe coating is thicker at corners.