ESPTR: Radar Basics

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Prototype


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RADAR - echolocation

RAdio Detection And Ranging

detection ⟶ transmit some energy and watch it return

ranging ⟶ and measure the round-trip time

Electromagnetic version

1865 James Clerk Maxwell - theory of electromagnetic waves

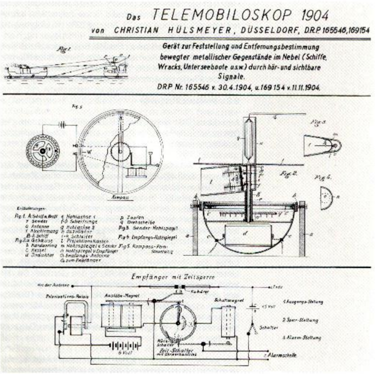
1886 Heinrich Hertz - experimental proof

1904 Christian Hülsmeyer - *Telemobiloskop*: ship collision avoidance apparatus, patented in Germany and UK; demonstration at the Rhine river in Cologne, DE.

...

1939-1945 Chain Home, Klein Heidelberg and other installations

Telemobiloskop



Chain Home

Frequency:	20 to 30 MHz
Peak Power:	350 kW (750 kW)
p.r.f.:	25 and 12.5 p.p.s.
Pulse Length:	20 us

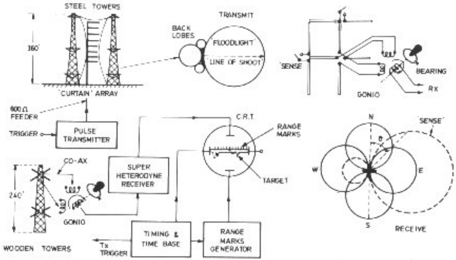
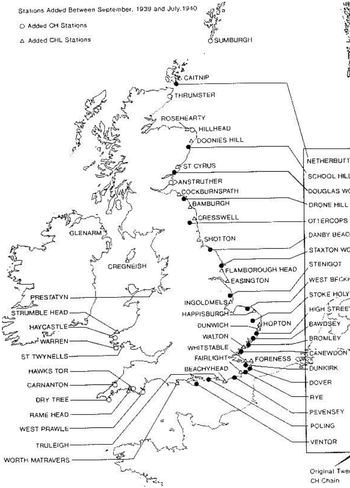
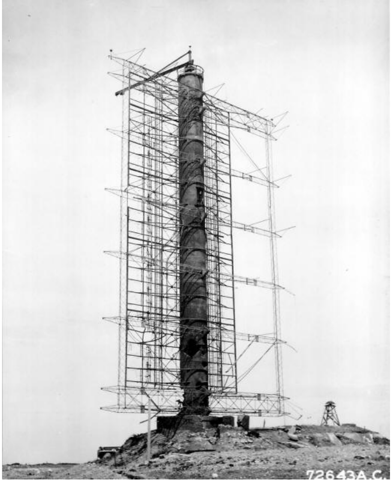


Fig. 1. Principles of CH (Chain Home) R.D.F. system



Klein Heidelberg Parasit



Range 400 km, accuracy 1 - 2 km and 1 degree

Radar equation

Transmit-reflect-receive-detect:
http://commons.wikimedia.org/wiki/File:Radarops.gif
Received power: radar *range* equation

$$P_r = \frac{P_t G_t A_r \sigma F^4}{(4\pi)^2 R_t^2 R_r^2}$$

- P_t transmitter power
- G_t gain of the transmitting antenna $G = 4\pi A_{eff}/\lambda^2$
- A_r effective aperture (area) of the receiving antenna
- σ radar cross section, or scattering coefficient, of the target
- F pattern propagation factor
- R_t distance from the transmitter to the target
- R_r distance from the target to the receiver.

2x range $\longrightarrow 2^4 = 16$x power needed ...

Signal model

Transmit:

$$x_T(t) = A_T(t)e^{j\phi_T(t)}$$

Receive:

$$x_R(t) = A_T(t - R(t)/c)e^{j\phi_T(t-R(t)/c)}$$

simple case: $\phi_T(t) = \omega t + \phi_M(t)$, $R(t) = R_0 + vt$

$$x_R(t) = A_T(t - R_0/c - vt/c)e^{j(\omega(t-R_0/c-vt/c)+\phi_M(t-R_0/c-vt/c))}$$

$$x_R(t) = A_T(t-R_0/c-vt/c)e^{j(\omega t)}e^{-j\omega(R_0/c)}e^{-j\omega vt/c}e^{j\phi_M(t-R_0/c-vt/c)}$$

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Baseband:

$$x_R(t) = A_T(t-R_0/c-vt/c)e^{j\phi_M(t-R_0/c-vt/c)} \qquad e^{-j\omega(R_0/c)}e^{-j\omega vt/c}$$

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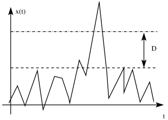
Detection



$\longrightarrow$compare signal with threshold

$$P_r > P_{noise} \cdot D \quad \longrightarrow \quad \text{declare a target}$$

with integration (by a matched filter) over t_i seconds

$$\frac{P_t G_t A_r \sigma F^4 t_i B}{(4\pi)^2 R_t^2 R_r^2} > kTBD$$

so the minimum detected object RCS

$$\sigma_{min} = \frac{(4\pi)^2 R_t^2 R_r^2 kTD}{P_t G_t A_r \sigma F^4 t_i}$$

We sometimes express σ in dBsm (dB w.r.t. square meter).

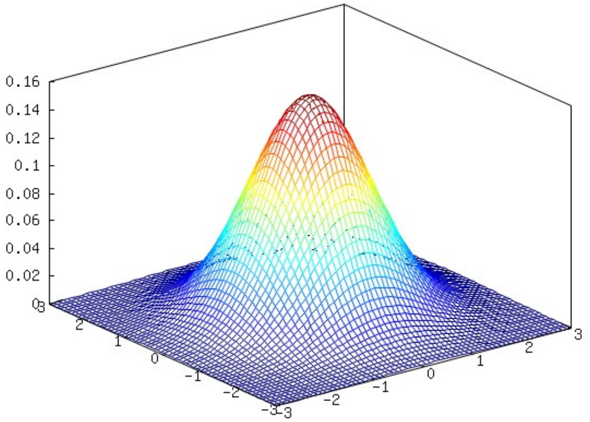
Detection threshold

$x(t) < D \longrightarrow H_0$ Hypothesis 0: only noise
$x(t) > D \longrightarrow H_1$ Hypothesis 1: noise + signal
Maximize P_d (detection), keep P_{fa} (false alarm) low.
The threshold D set above:

- Noise (thermal etc)
- Clutter (unwanted echoes)
- Multipath
- Jamming (intentionally malicoius transmitters)
- Interferences (other equipment, e.g. other radars)

Improvements: matched filter (S$\uparrow$), interference cancellation (C$\downarrow$)
Typical: SNR $\approx$ 13 dB
Adaptation: CFAR

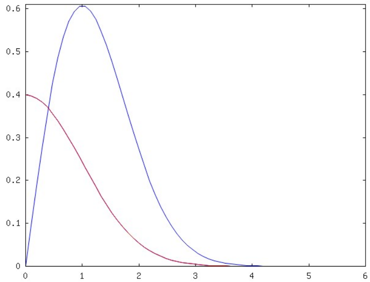
H0: Noise distribution (complex)



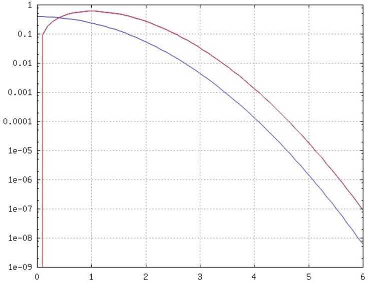
Two-dimensional (imag / real) gaussian distribution

H0: Noise distribution (abs)

abs(gaussian+j*gaussian)=rayleigh



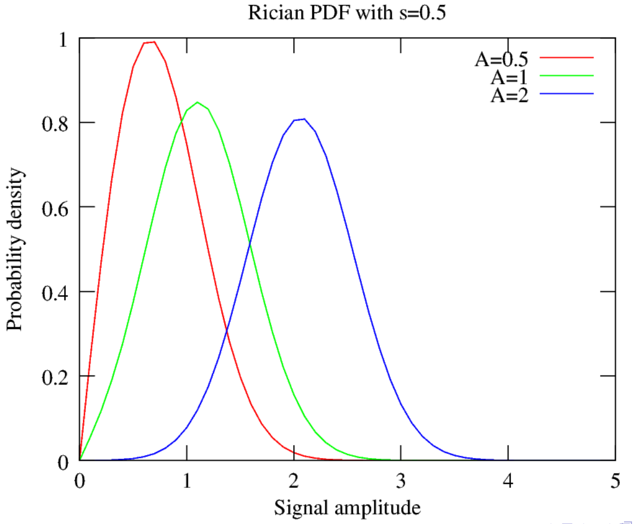
lin scale



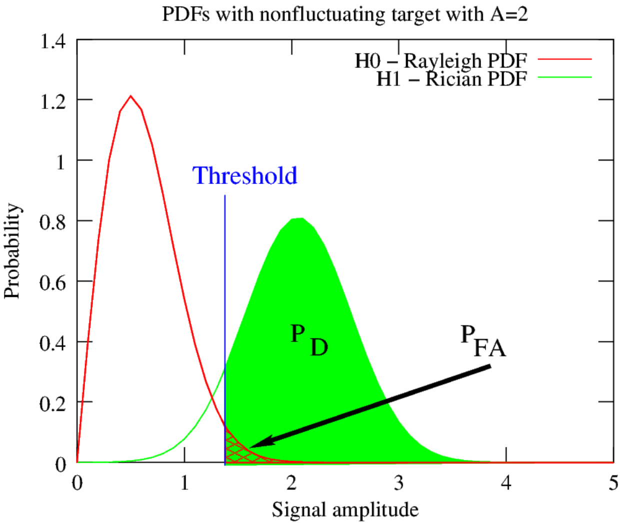
log scale

H1: Signal + noise distribution (abs)

abs((gaussian+j*gaussian)+constant A)=rician



Neyman-Pearson detector



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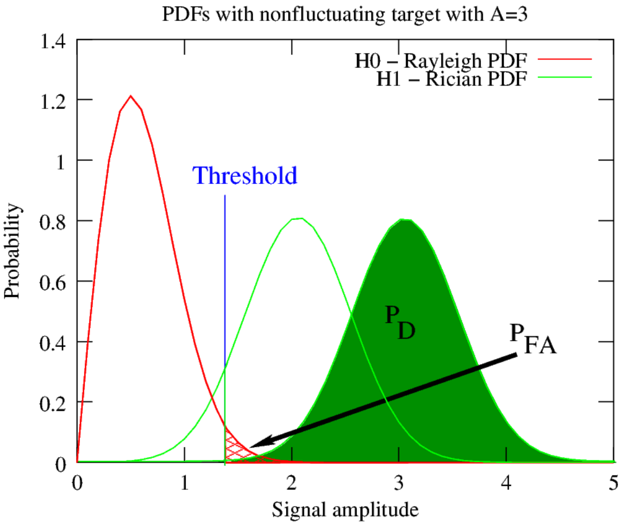
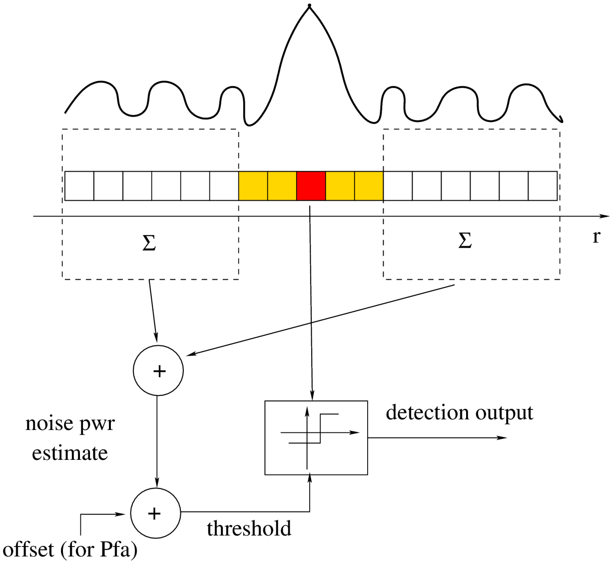


CFAR- Constant False Alarm Rate



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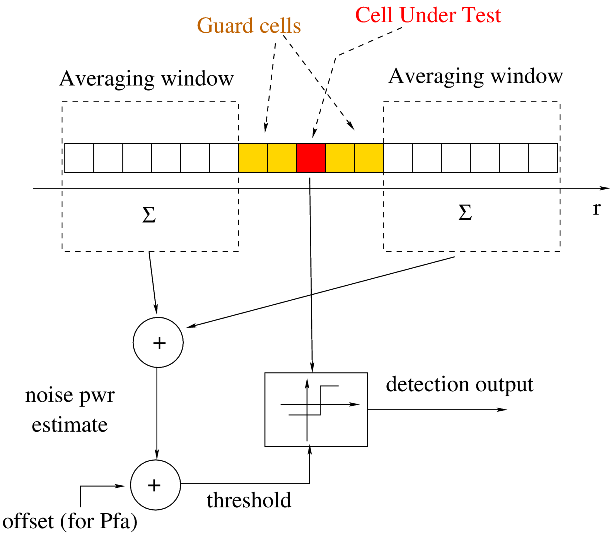
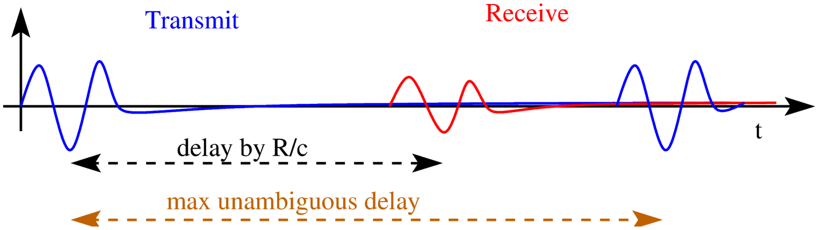


Range measurement

⟶signal delay measurement



- Max *unambiguous* range limited by modulation period
- Min range limited by transmit signal entering the receiver (in pulsed radar)
  - Antenna separation
  - T/R switch + receiver safety (ionised gas + pin diode)

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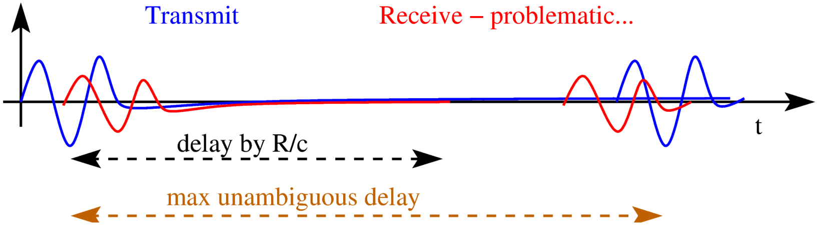

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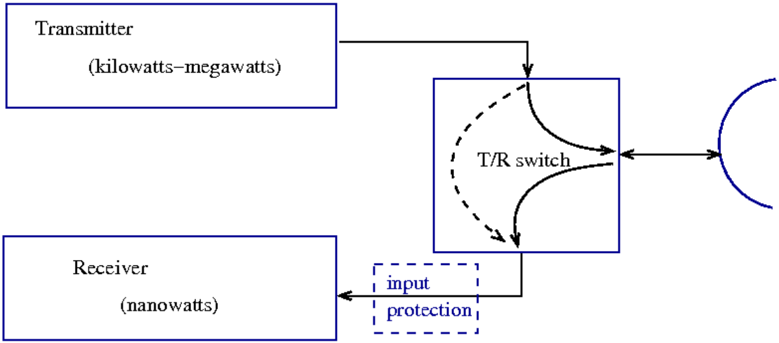
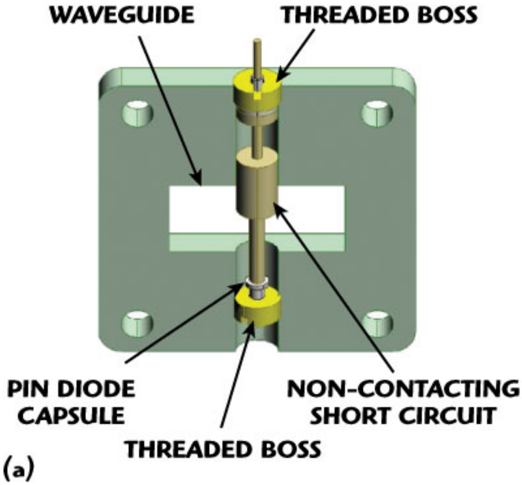
Transmit/receive switch



Make friends with good microwave engineers . . .

Receiver input protection



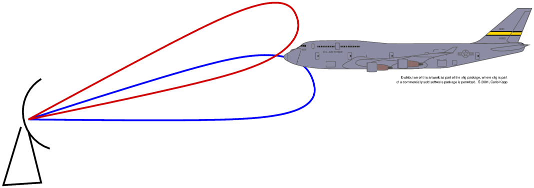
Velocity measurement

⟶Doppler shift measurement

$$x_R(t) = A_T(t - R_0/c - vt/c)e^{j\phi_M(R_0/c+vt/c)}\, e^{j(\omega t)} e^{-j\omega(R_0/c)} e^{-j\omega vt/c}$$

- Min velocity: ground/meteo clutter
- Max velocity (frequency): inverse of modulation period (PRI)

Angle measurement



- azimuth
- elevation

Methods

- Scanning: mechanical, electronic
- Monopulse techniques (multielement antenna)
  - Power ratio
  - Sigma-Delta (power)
  - Phased arrays