# ESPTR: Radar Basics

Jacek Misiurewicz

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# Prototype


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# RADAR - echolocation

RAdio Detection And Ranging

detection $\longrightarrow$ transmit some energy and watch it return

ranging $\longrightarrow$ and measure the round-trip time

# Electromagnetic version

1865 James Clerk Maxwell - theory of electromagnetic waves

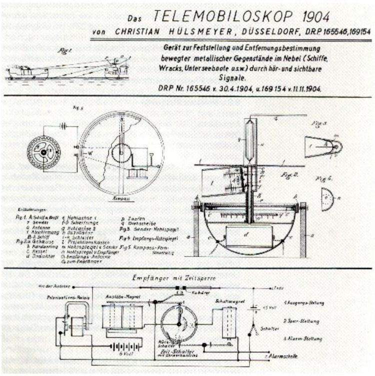
1886 Heinrich Hertz - experimental proof

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 |

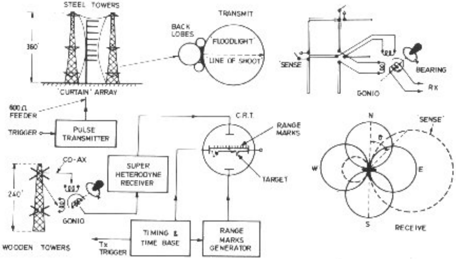
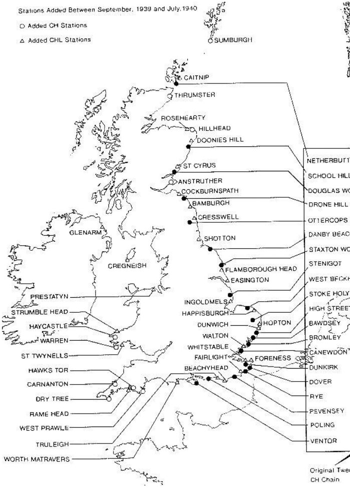
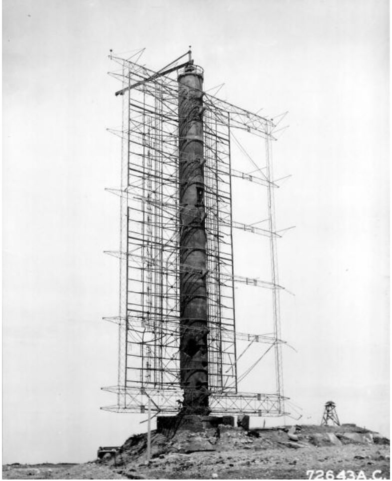



*Fig. 1. Principles of CH (Chain Home) R.D.F. system*



# 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
- $\sigma$ 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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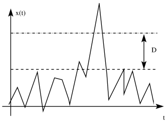
# Detection




⟶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

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

We sometimes express $\sigma$ 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:

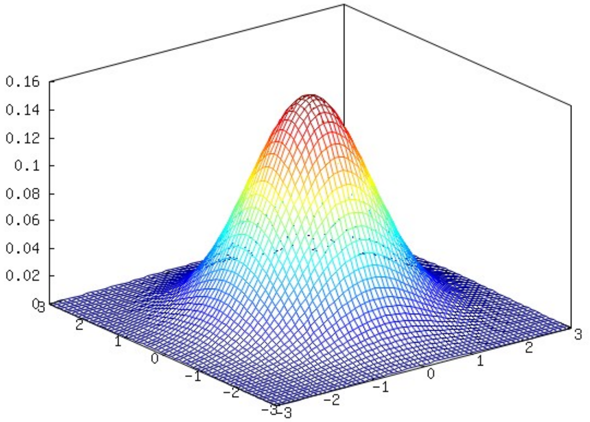
- Noise (thermal etc)
- Clutter (unwanted echoes)
- Multipath
- Jamming (intentionally malicious transmitters)
- Interferences (other equipment, e.g. other radars)

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

# Noise and clutter

You can fight noise, jamming and interferences by using more power or better matched filtering.
You cannot fight clutter or multipath this way.

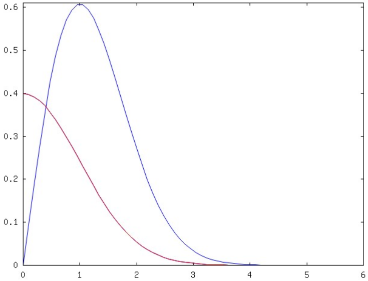
# H0: Noise distribution (complex)



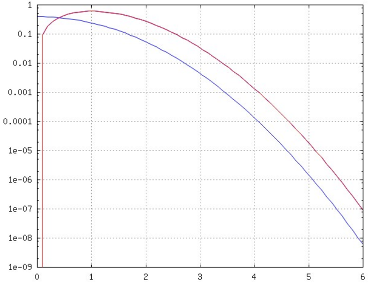

Two-dimensional (imag / real) gaussian distribution

# H0: Noise distribution (abs)

abs(gaussian+j*gaussian)=rayleigh



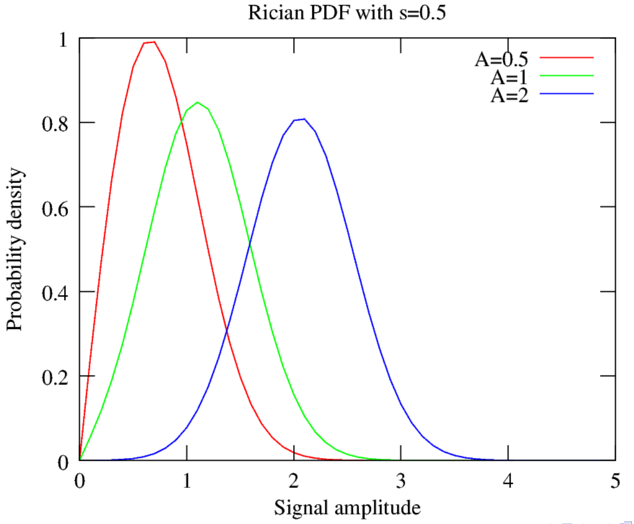

lin scale



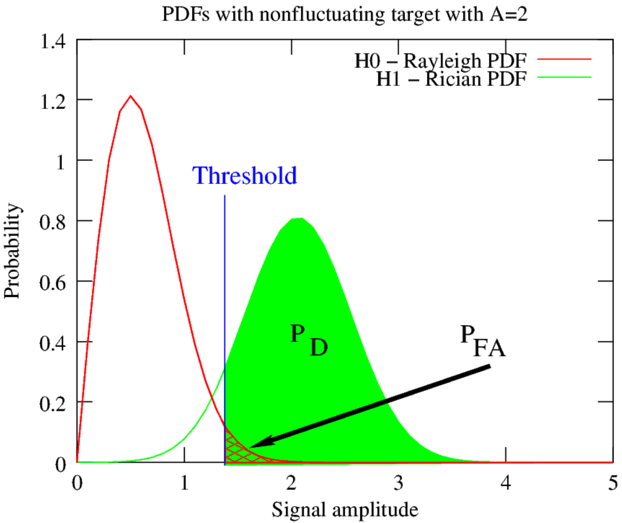

log scale

# H1: Signal + noise distribution (abs)

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



# Neyman-Pearson detector



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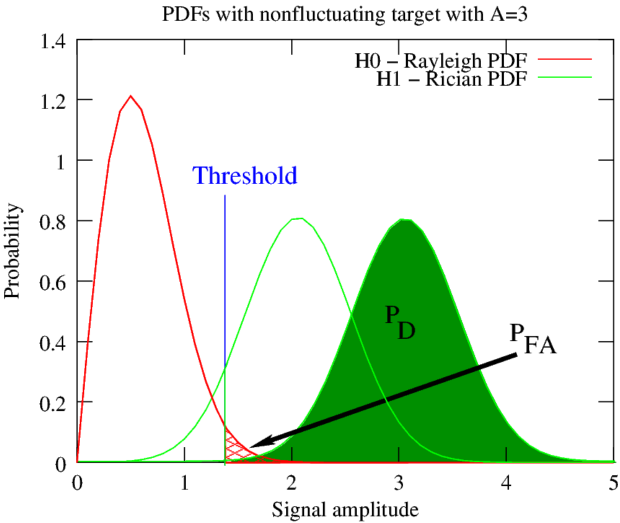
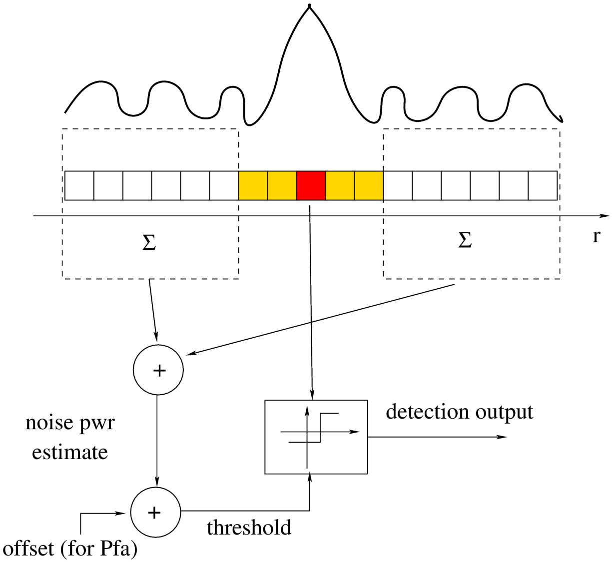


# CFAR- Constant False Alarm Rate



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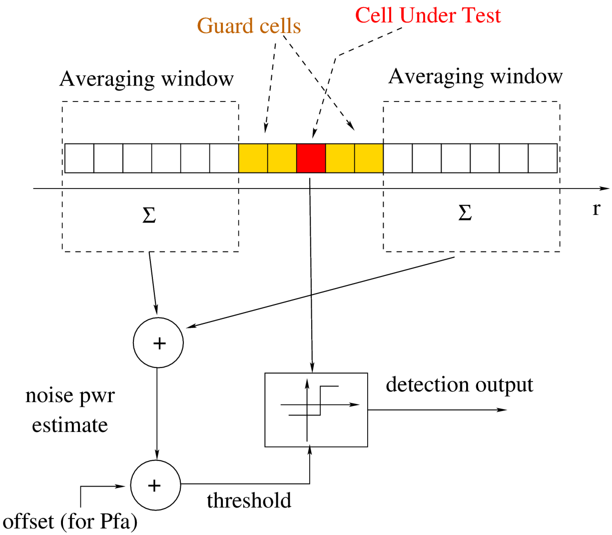
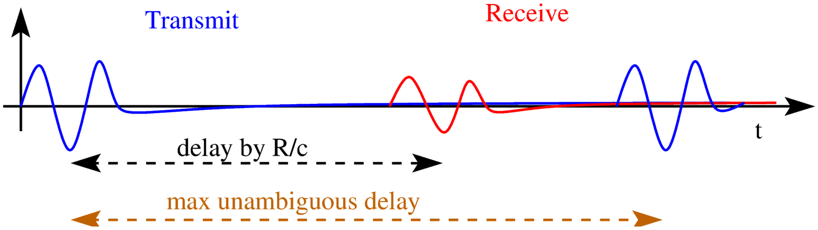


# Range measurement

⟶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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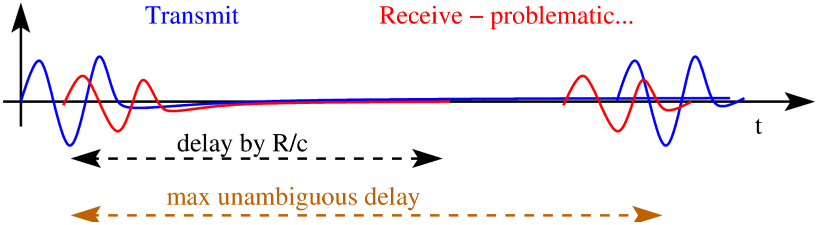
⟶signal delay measurement

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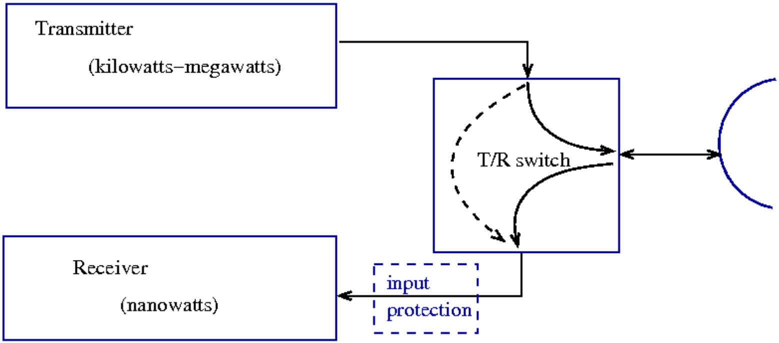
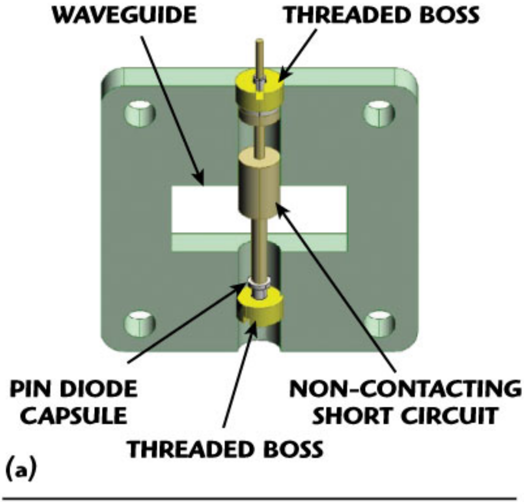
# Transmit/receive switch




Make friends with good microwave engineers . . .

# Receiver input protection



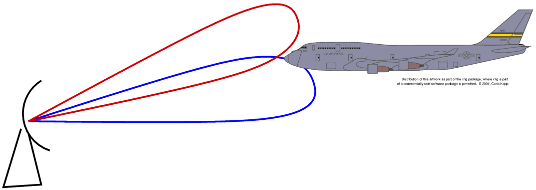
# Velocity measurement

$\longrightarrow$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