

# ESPTR: Radar Basics

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# Prototype



# Electromagnetic version

- 1865 James Clerk Maxwell - theory of electromagnetic waves
- 1886 Heinrich Hertz - experimental proof
- 1904 Christian Hülsmeier - *Telemobiloskop*: ship collision avoidance apparatus, patented in Germany and UK; demonstration at the Rhine river in Cologne, DE.
- ...
- 1939-1945 Home Chain and other installations

# Radar equation

Transmit-reflect-receive-detect:

<http://commons.wikimedia.org/wiki/File:Radarsops.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  $G = 4\pi A_{\text{eff}}/\lambda^2$

$A_r$  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  $\longrightarrow 2^4 = 16x$  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:  $\phi_T(t) = \omega t + \phi_M(t)$ ,  $R(t) = R_0 + vt$

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

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

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

# 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

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

We sometimes express  $\sigma$  in dBsm (dB w.r.t. square meter).

# Detection threshold

Maximize  $P_d$  (detection), keep  $P_{fa}$  (false alarm) low.  
The threshold  $D$  set above:

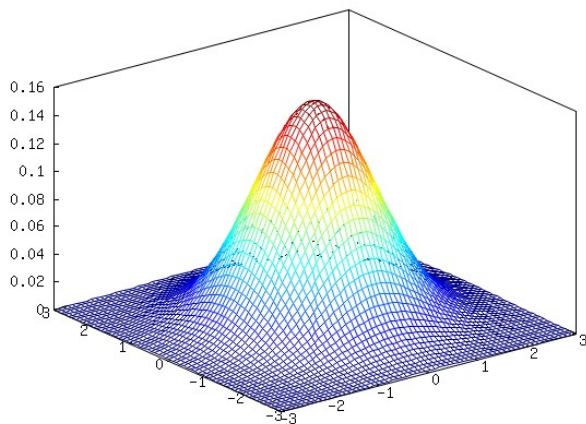
- ▶ Noise (thermal etc)
- ▶ Clutter (unwanted echoes)
- ▶ Multipath
- ▶ Jamming (intentionally malicious transmitters)
- ▶ Interferences (other equipment, e.g. other radars)

Improvements: matched filter ( $S\uparrow$ ), interference cancellation ( $C\downarrow$ )

Typical: SNR  $\approx 13$  dB

Adaptation: CFAR

# Noise distribution (complex)

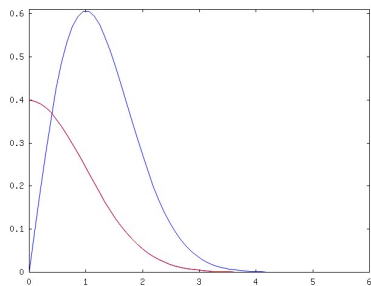


Two-dimensional (imag / real) gaussian distribution

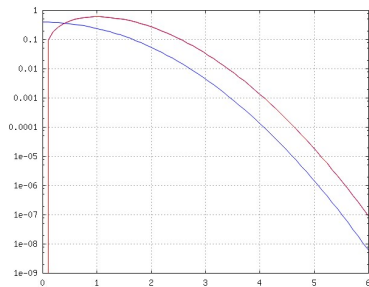


# Noise distribution (abs)

$\text{abs}(\text{gaussian} + j * \text{gaussian}) = \text{rayleigh}$



lin scale



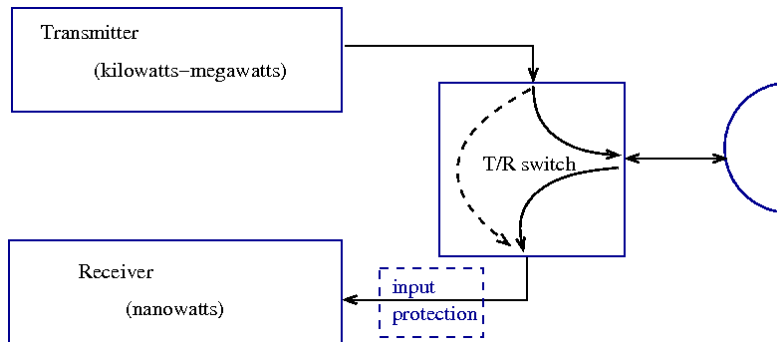
log scale

# Range measurement

→ signal delay measurement

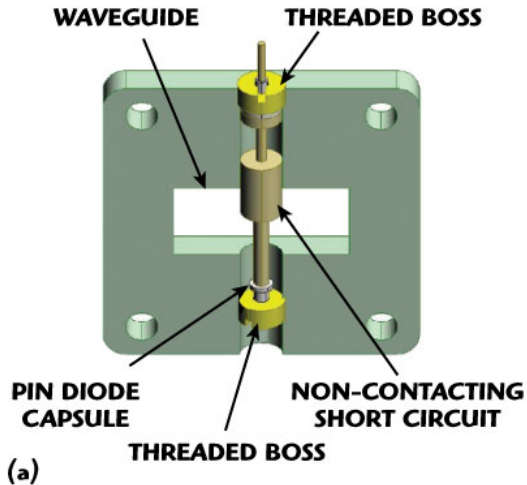
- ▶ Max *unambiguous* range limited by modulation period
- ▶ Min range limited by transmit signal entering the receiver (in pulsed radar)
  - ▶ Antenna separation
  - ▶ T/R switch + receiver safety (ionised gas + pin diode)

# 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

# Angle measurement

- ▶ azimuth
- ▶ elevation

## Methods

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