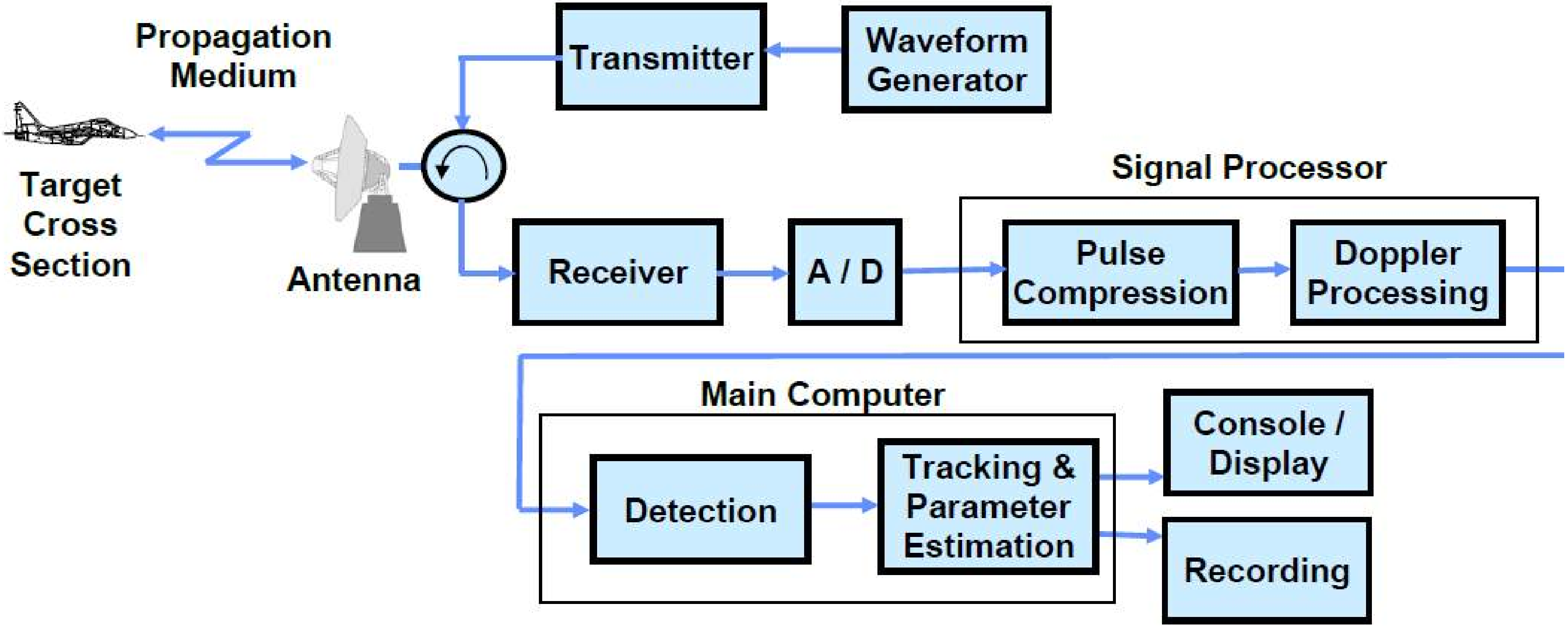
Radar Systems

Lecture 2. The Radar Equation

구 자 열

Introduction – The Radar Range Equation



The Radar Range Equation Connects:

1. Target Properties - e.g. Target Reflectivity (radar cross section)
2. Radar Characteristics - e.g. Transmitter Power, Antenna Aperture
3. Distance between Target and Radar - e.g. Range
4. Properties of the Medium - e.g. Atmospheric Attenuation.

차　　례

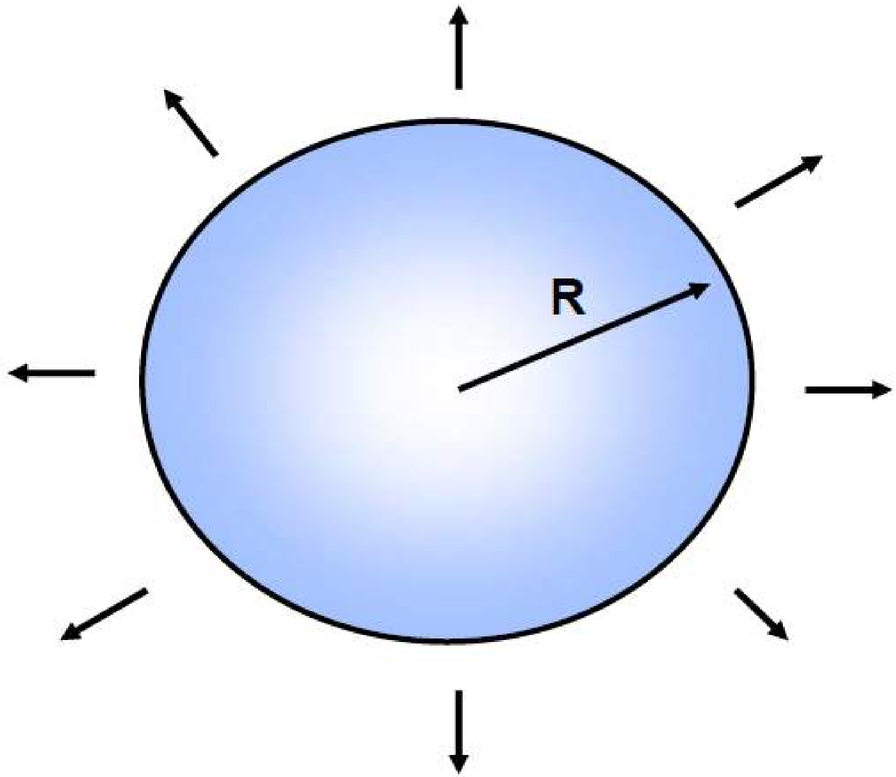
- Introduction
- Introduction to Radar Equation
- Surveillance Form of Radar Equation
- Radar Losses
- Example

Radar Range Equation

Power density from uniformly radiating antenna transmitting spherical wave

$$\frac{P_t}{4 \pi R^2}$$

P_t = peak transmitter power
R = distance from radar



Radar Range Equation (continued)

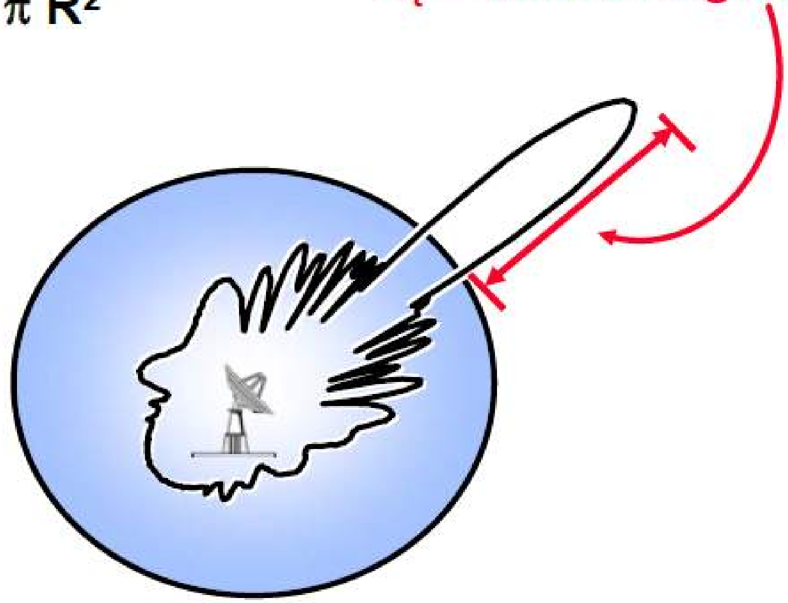
Power density from isotropic antenna $\frac{P_t}{4 \pi R^2}$

P_t = peak transmitter power

R = distance from rada

Power density from directive antenna $\frac{P_t G_t}{4 \pi R^2}$

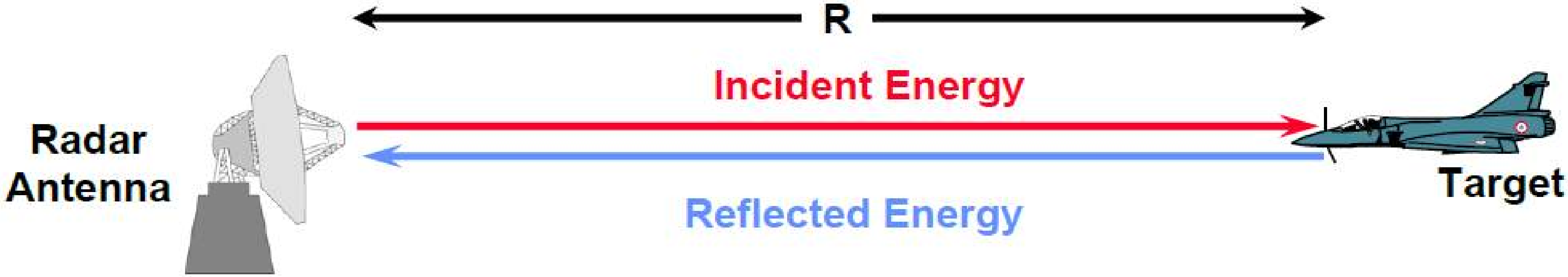
G_t = transmit gain



Gain is the radiation intensity of the antenna in a given direction over that of an isotropic (uniformly radiating) source

$$\text{Gain} = 4 \pi A / \lambda^2$$

Definition of Radar Cross Section (RCS or σ)



Radar Cross Section (RCS or σ) is a measure of the energy that a radar target intercepts and scatters back toward the radar

Power of reflected signal at target

$$\frac{P_t G_t \sigma}{4 \pi R^2}$$

σ = radar cross section units (meters)^2

Power density of reflected signal at the radar

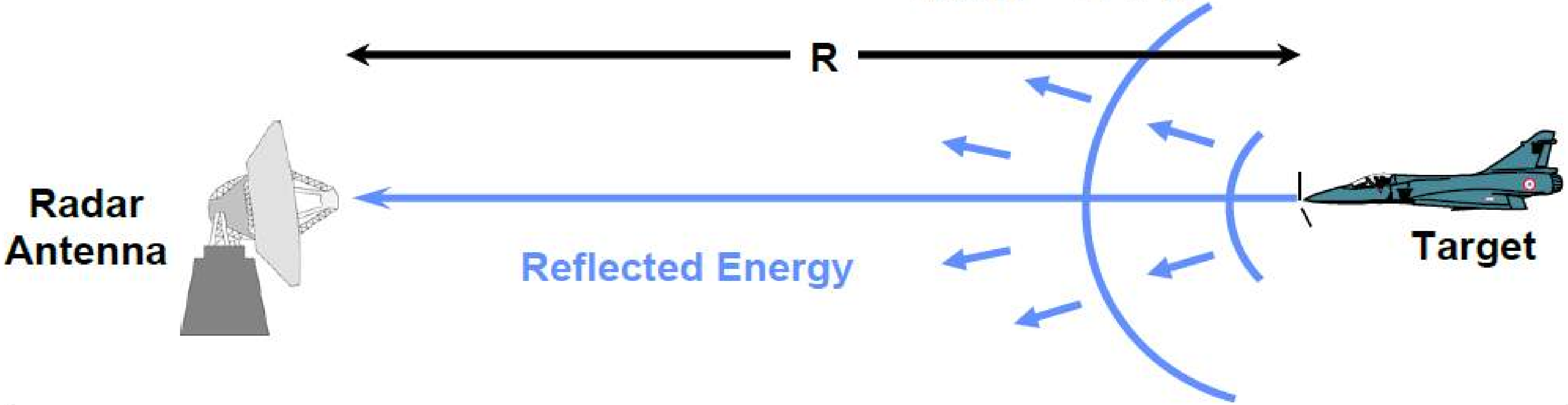
$$\frac{P_t G_t}{4 \pi R^2} \frac{\sigma}{4 \pi R^2}$$

Power density of reflected signal falls off as $(1/R^2)$

Radar Range Equation (continued)

Power density of reflected signal at radar

$$\frac{P_t G_t}{4 \pi R^2} \frac{\sigma}{4 \pi R^2}$$



The received power = the power density at the radar times the area of the receiving antenna

Power of reflected signal from target and received by radar

$$P_r = \frac{P_t G_t}{4 \pi R^2} \frac{\sigma A_e}{4 \pi R^2}$$

P_r = power received

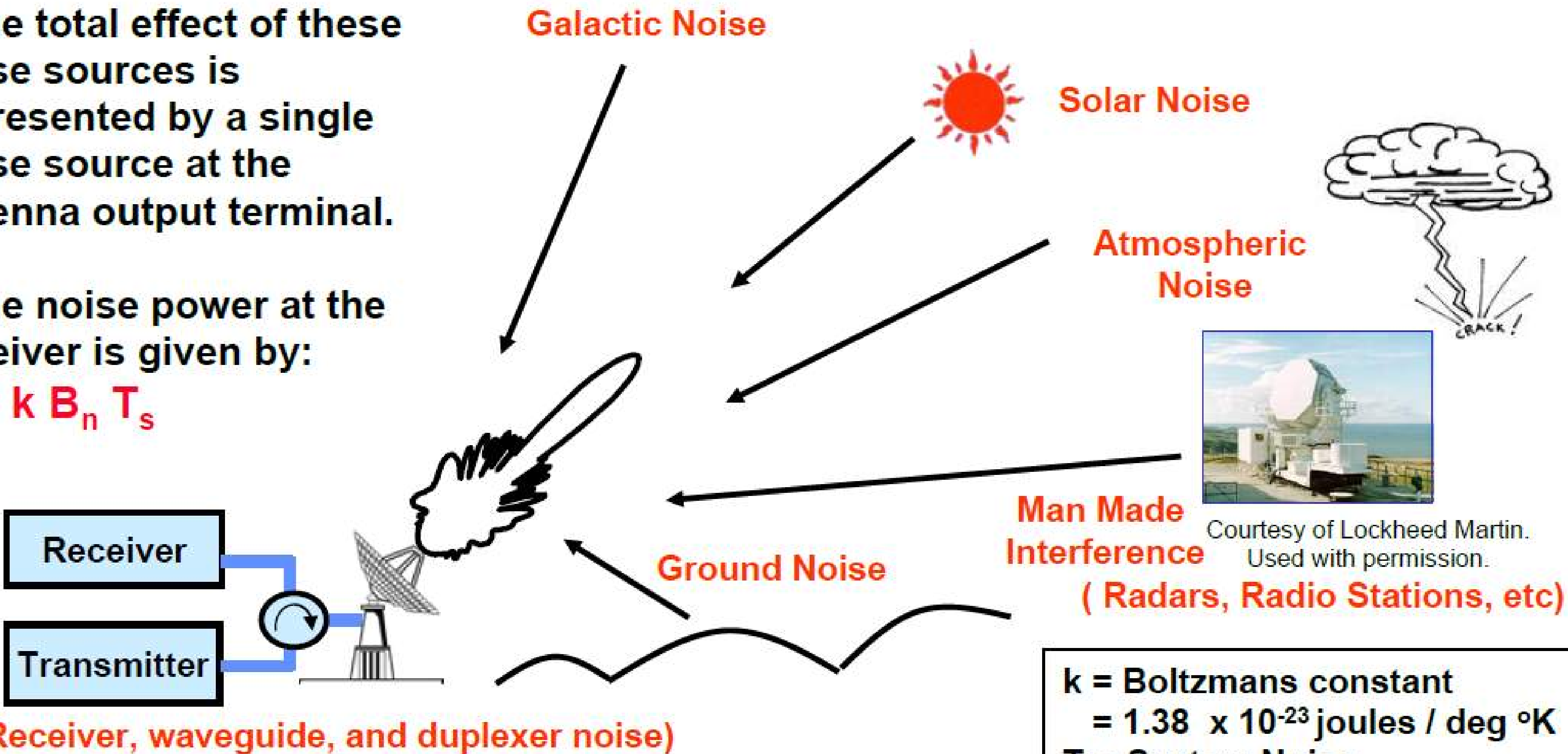
A_e = effective area of receiving antenna

Sources of Noise Received by Radar

- The total effect of these noise sources is represented by a single noise source at the antenna output terminal.

- The noise power at the receiver is given by:

$N = k\ B_n\ T_s$



Noise from Many Sources Competes with the Target Echo

k = Boltzmans constant
$= 1.38 \times 10^{-23}$ joules / deg °K
T_s = System Noise Temperature
B_n = Noise bandwidth of receiver

Radar Range Equation (continued)

Signal Power reflected from target and received by radar

$$P_r = \frac{P_t G_t}{4 \pi R^2} \frac{\sigma A_e}{4 \pi R^2}$$

Average Noise Power

$$N = k T_s B_n$$

Signal to Noise Ratio

$$S / N = P_r / N$$

<u>Assumptions</u> :
$G_t = G_r$
L = Total System Losses
$T_o = 290° K$

$$\boxed{S / N = \frac{P_t G^2 \lambda^2 \sigma}{(4 \pi)^3 R^4 k T_s B_n L}}$$

Signal to Noise Ratio (S/N or SNR) is the standard measure of a radar's ability to detect a given target at a given range from the radar

" S/N = 13 dB on a 1 m^2 target at a range of 1000 km"

radar cross section of target

System Noise Temperature

- The System Noise Temperature, T_S , is divided into 3 components :

$$T_s = T_a + T_r + L_r T_e$$

- T_a is the contribution from the antenna
  - Apparent temperature of sky (from graph)
  - Loss within antenna
- T_r is the contribution from the RF components between the antenna and the receiver
  - Temperature of RF components
- L_r is the loss of input RF components
- T_e is the temperature of the receiver
  - Noise factor of receiver

차   례

- **Introduction**
- **Introduction to Radar Equation**
- **Surveillance Form of Radar Equation**
- **Radar Losses**
- **Example**

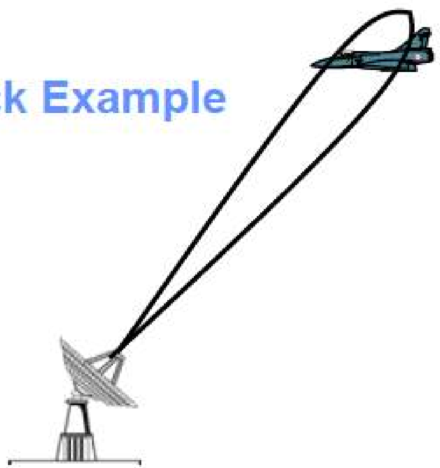
Track Radar Range Equation

Track Radar Equation

$$S / N = \frac{P_t \, G^2 \lambda^2 \sigma}{(4 \pi)^3 R^4 k T_s B_n L}$$

- When the location of a target is known and the antenna is pointed toward the target.

Track Example



Track & Search Radar Range Equations

Track Radar Equation

$$S/N = \frac{P_t\, G^2 \lambda^2 \sigma}{(4\pi)^3 R^4 k\, T_s\, B_n\, L}$$

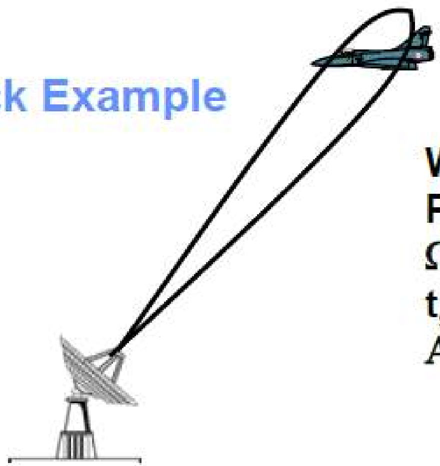
- When the location of a target is known and the antenna is pointed toward the target.

Search Radar Equation

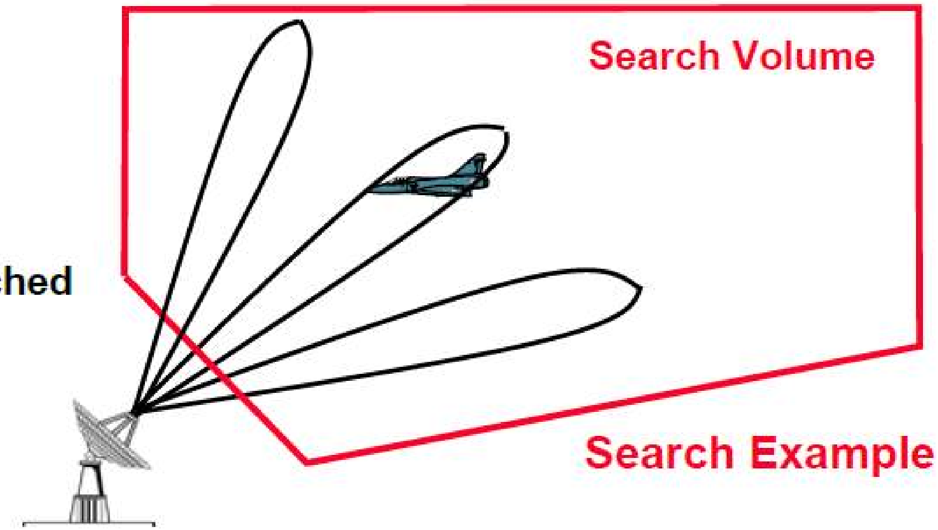
$$\boxed{S/N = \frac{P_{av}\, A_e\, t_s\, \sigma}{4\pi\Omega\, R^4 k\, T_s\, L}}$$

- When the target's location is unknown, and the radar has to search a large angular region to find it.

Track Example



Where:
P_{av} = average power
Ω = solid angle searched
t_s = scan time for Ω
A_e = antenna area



Search Radar Range Equation

$$\boxed{S / N = \frac{P_{av} \; A_e \, t_s \, \sigma}{4 \, \pi \, \Omega \;\; R^4 \, k \, T_s \;\; L}}$$

Re-write as:

f (design parameters) = g (performance parameters)

$$\frac{P_{av} \; A_e}{k T_s \; L} = \frac{4 \, \pi \, \Omega \, R^4 \, (S/N)}{\sigma \; t_s}$$

Angular coverage

Range coverage

Measurement quality

Time required

Target size

Scaling of Radar Equation

$$\frac{S}{N} = \frac{P_{av}\, A_e\, t_s\, \sigma}{4\pi\, R^4\, \Omega\, k\, T_s\, L} \Rightarrow P_{av} = \frac{4\pi\, R^4\, \Omega\, k\, T_s\, L\, (S/N)}{A_e\, t_s\, \sigma}$$

- Power required is:
  - Independent of wavelength
  - A very strong function of R
  - A linear function of everything else

Example Radar Can Perform Search at 1000 km Range
How Might It Be Modified to Work at 2000 km ?

Solutions Increasing R by 3 dB (x 2) Can Be Achieved by:

1. Increasing P_{av} by 12 dB (x 16)

or 2. Increasing Diameter by 6 dB (A by 12 dB)

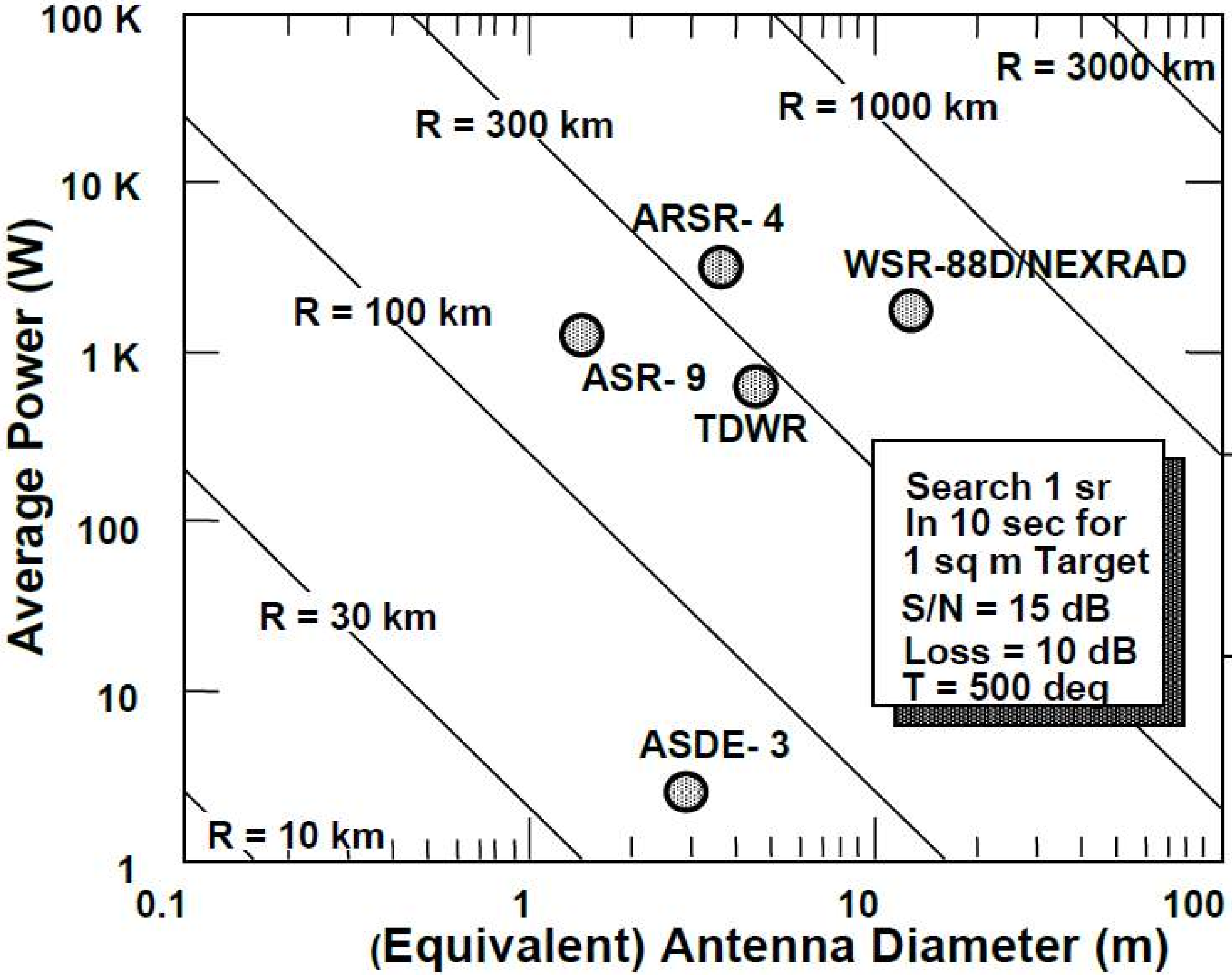
or 3. Increasing t_s by 12 dB

or 4. Decreasing Ω by 12 dB

or 5. Increasing σ by 12 dB

or 6. An Appropriate Combination of the Above

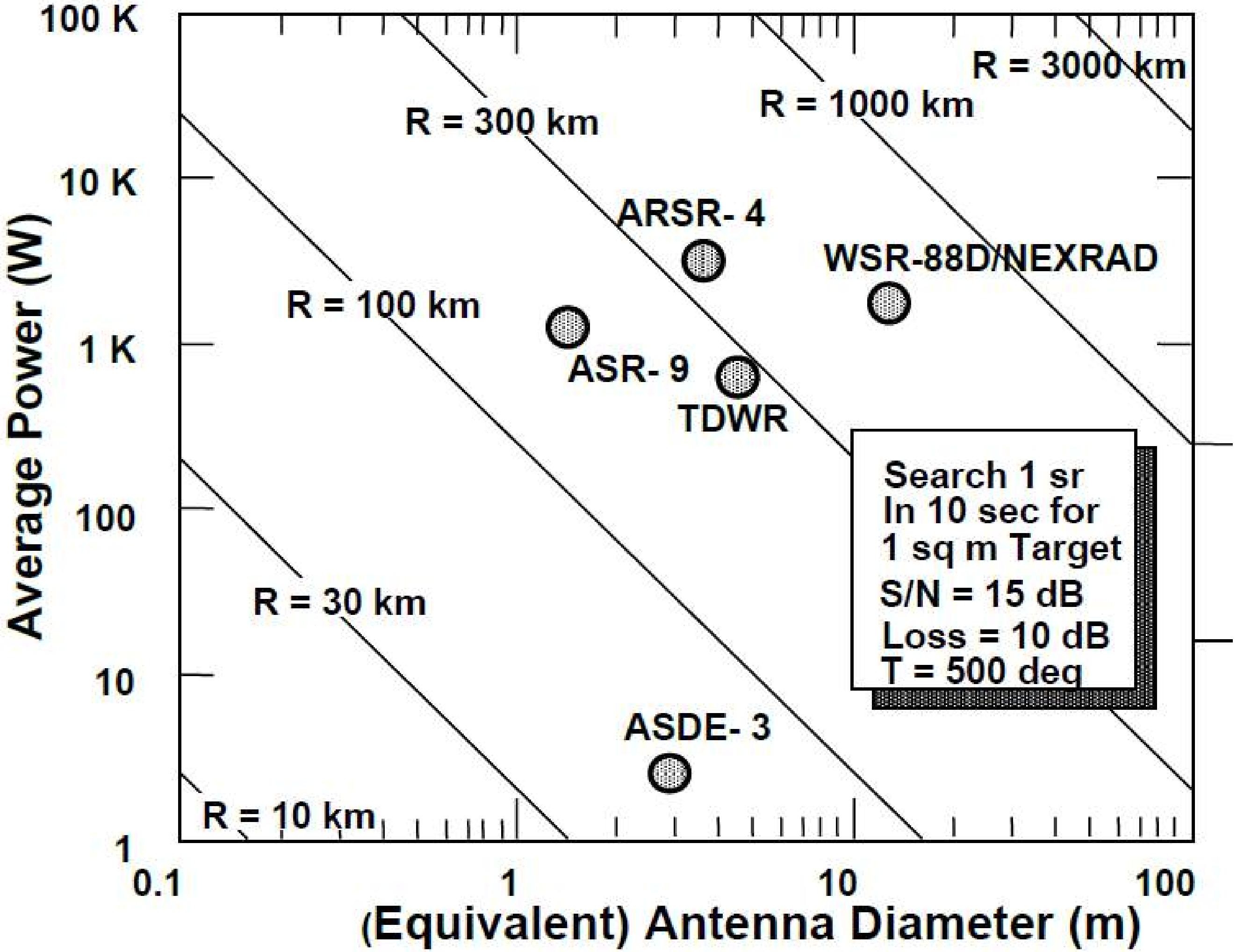
Search Radar Performance



ASR- 9
Airport Surveillance Radar

Courtesy of Northrop Grumman.
Used with permission.

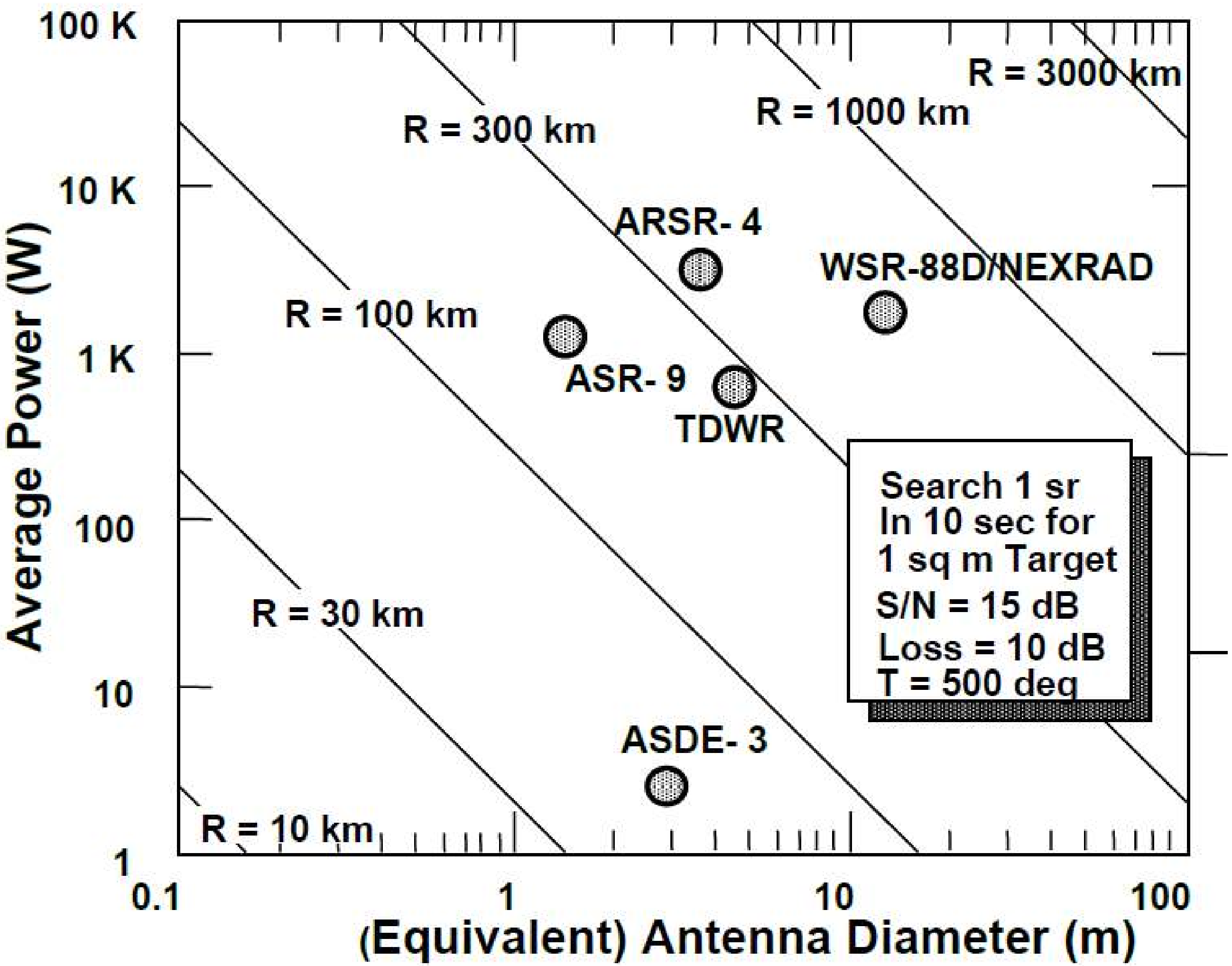
Search Radar Performance



ASDE- 3
Airport Surface Detection Equipment

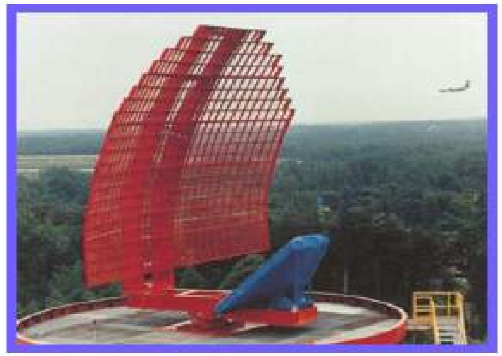
Courtesy Lincoln Laboratory

Search Radar Performance



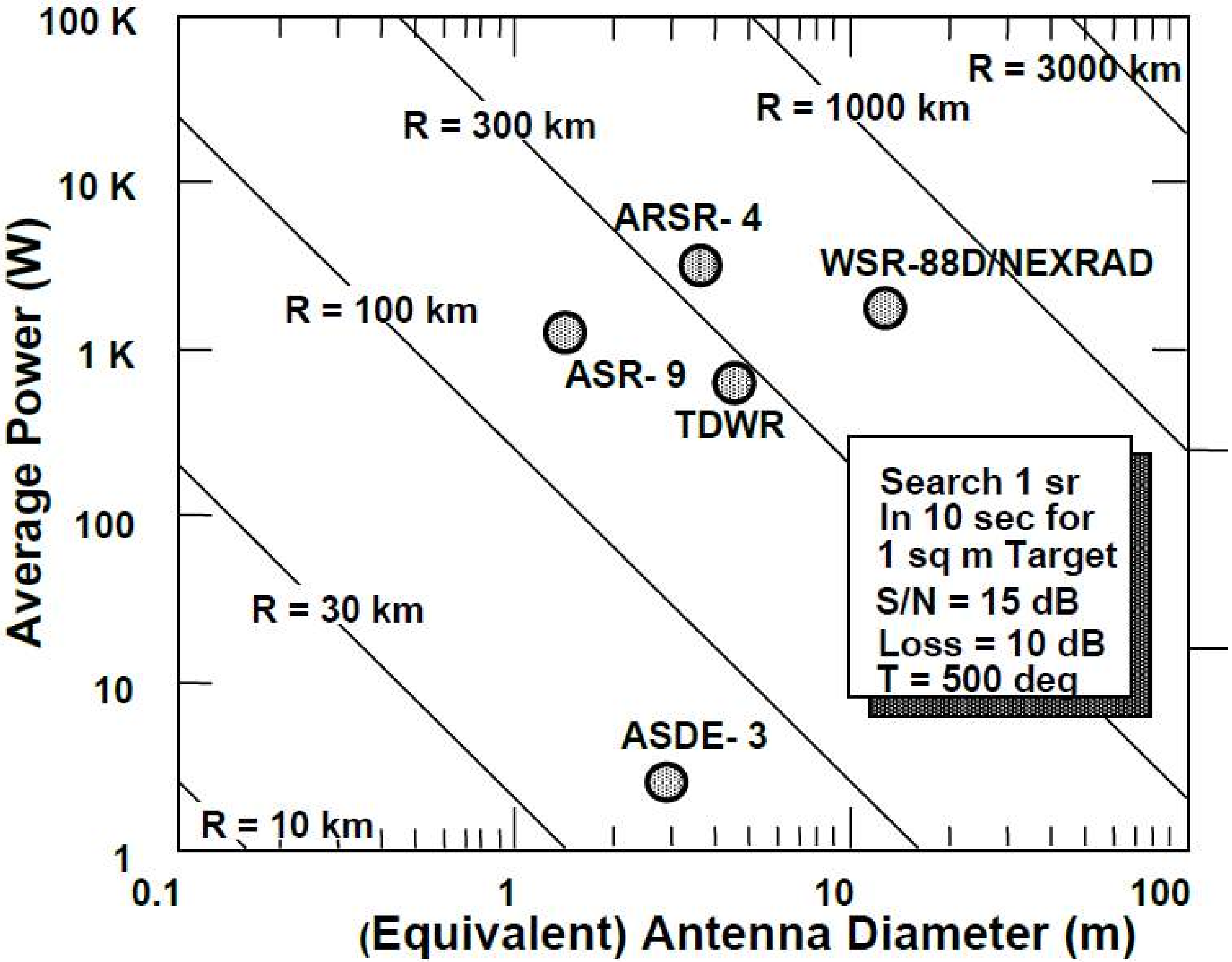
ARSR- 4
Air Route Surveillance Radar

ARSR- 4 Antenna
(without Radome)



Courtesy of Northrop Grumman.
Used with permission.

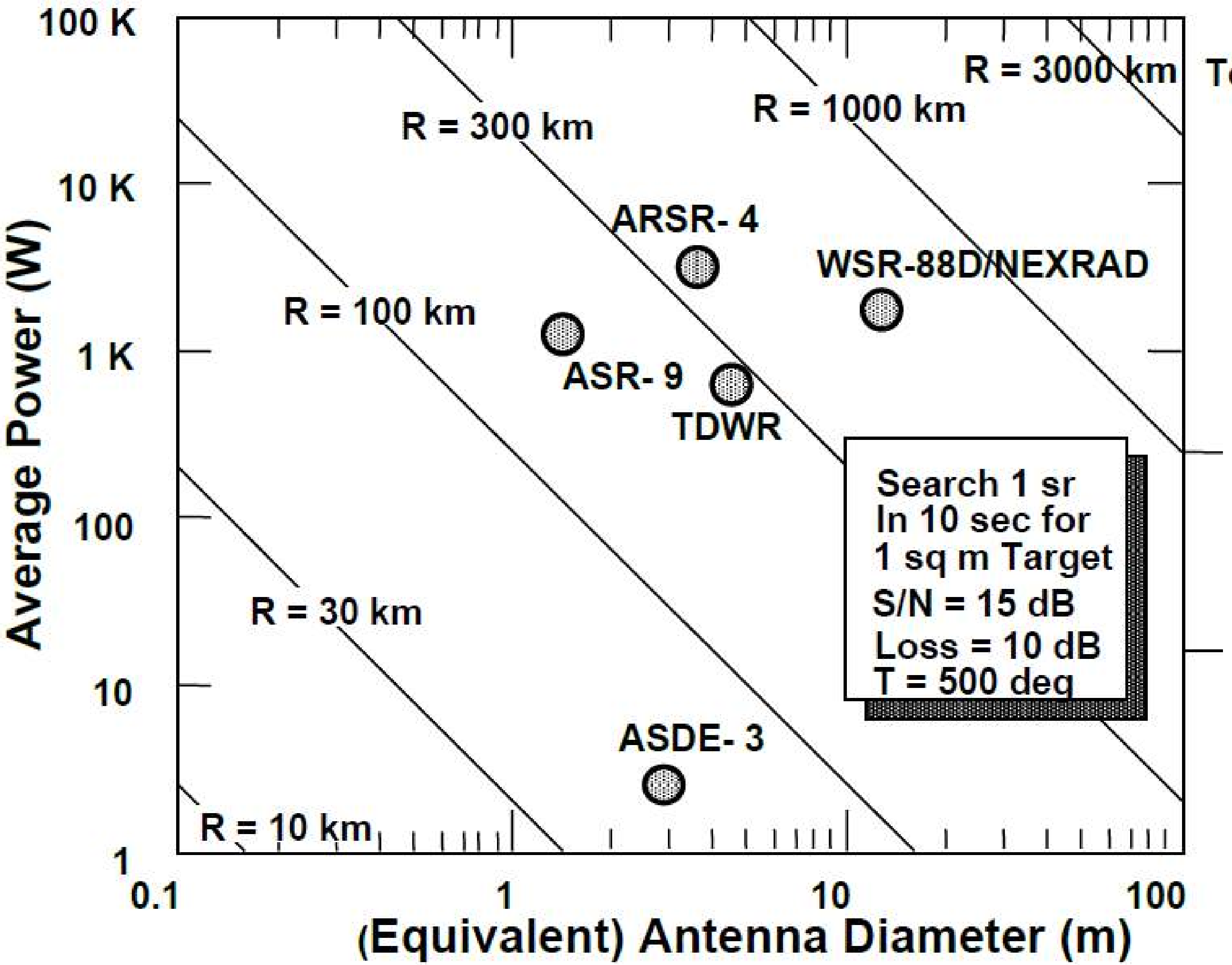
Search Radar Performance



WSR-88D / NEXRAD

Courtesy of NOAA.

Search Radar Performance



TDWR
Terminal Doppler Weather Radar

Courtesy of Raytheon.
Used with permission

차 례

- Introduction
- Introduction to Radar Equation
- Surveillance Form of Radar Equation
- Radar Losses
- Example

Loss Terms for Radar Equation

Transmit Losses

- Radome
- Waveguide Feed
- Waveguide
- Circulator
- Low Pass Filters
- Rotary Joints
- Antenna Efficiency
- Beam Shape
- Scanning
- Quantization
- Atmospheric
- Field Degradation

Receive Losses

- Radome
- Waveguide Feed
- Waveguide
- Combiner
- Rotary Joints
- Receiver Protector
- Transmit / Receive Switch
- Antenna Efficiency
- Beam Shape
- Scanning
- Quantization
- Weighting
- Non-Ideal Filter
- Doppler Straddling
- Range Straddling
- CFAR
- Atmospheric
- Field Degradation

Examples of Losses in Radar Equation

- Beam Shape Loss
  - Radar return from target with scanning radar is modulated by shape of antenna beam as it scans across target. Can be 2 to 4 dB
- Scanning Antenna Loss
  - For phased array antenna, gain of beam off boresight less than that on boresight
- Plumbing Losses
  - Transmit waveguide losses
  - Rotary joints, circulator, duplexer
- Signal Processing Loss
  - A /D Quantization Losses
  - Adaptive thresholding (CFAR) Loss
  - Range straddling Loss
  - Range and Doppler Weighting

Examples of Losses in Radar Equation

- Atmospheric Attenuation Loss
  - Radar beam attenuates as it travels through atmosphere (2 way loss)
- Integration Loss
  - Non coherent integration of pulses not as efficient as coherent integration
- Margin (Field Degradation) Loss
  - Characteristics of radar deteriorates over time.(3 dB not unreasonable
    - Water in transmission lines
    - Deterioration in receiver noise figure
    - Weak or poorly tuned transmitter tubes

차 례

- Introduction
- Introduction to Radar Equation
- Surveillance Form of Radar Equation
- Radar Losses
- Example

Example - Airport Surveillance Radar

- Problem : Show that a radar with the parameters listed below, will get a reasonable S / N on an small aircraft at 60 nmi.

<u>Radar Parameters</u>

Range	60 nmi
Aircraft cross section	1 m^2
Peak Power	1.4 Megawatts
Duty Cycle	0.000525
Pulsewidth	.6 microseconds
Bandwidth	1.67 MHz
Frequency	2800 MHz
Antenna Rotation Rare	12.8 RPM
Pulse Repetition Rate	1200 Hz
Antenna Size	4.9 m wide by 2.7 m high
Azimuth Beamwidth	1.35 °
System Noise Temp.	950 ° K

$\lambda = c / f = .103$ m

$G = 4\pi A / \lambda^2 = 15670\ m^2$
= 42 dB, (actually 33 dB with beam shaping losses)

Number of pulses per beamwidth = 21

Assume Losses = 8dB

AJOU UNIVERSITY

Example - Airport Surveillance Radar

$$S / N = \frac{P_t \, G^2 \, \lambda^2 \, \sigma}{(4\pi)^3 \, R^4 \, k \, T_s \, B_n \, L}$$

P_t = 1.4 Megawatts	R = 111, 000 m
G = 33 dB = 2000	T_s = 950 °K
$\lambda = .1$ m	B_n = 1.67 MHz
$\sigma = 1$ m^2	L = 8dB = 6.3
k = 1.38 x 10 $^{-23}$ w / Hz ° K	$(4\pi)^3$ = 1984

$$\frac{(1.4 \times 10^6 \text{ w})(2000)(2000)(.1\text{m})(.1\text{m})(1\text{m}^2)}{(1984)\,(1.11 \text{ X } 10^5 \text{ m})^4\,(1.38 \times 10^{-23} \text{ w / Hz °K})\,(950 \text{ °K})\,(6.3)\,(1.67 \times 10^6 \text{ Hz})}$$

$$\frac{5.6 \times 10^{+6+3+3-1-1}}{415 \times 10^{+3+20-23+2+6}} = \frac{5.6 \times 10^{+10}}{4.15 \times 10^{+2+3+20-23+2+6}} = \frac{5.6 \times 10^{+10}}{4.15 \times 10^{+10}} = 1.35 = 1.3 \text{ dB}$$

S / N = 1.3 dB per pulse (21 pulses integrated) => S / N per dwell = 14.5 dB

+ 13.2 dB

Example - Airport Surveillance Radar

dB Method

		(+)	(-)
Peak Power	1.4 MW	61.5	
$(\text{Gain})^2$	33 db	66	
$(\text{Wavelength})^2$	.1 m		20
Cross section	1 m^2	0	
$(4\pi)^3$	1984		33
$(\text{Range})^4$	111 km		201.8
k	1.38×10^{-23} w / Hz °K	228.6	
System temp	950		29.8
Losses	8 dB		8
Bandwidth	1.67 MHz		62.2
		+ 356.1	- 354.8

+ 1.3 dB

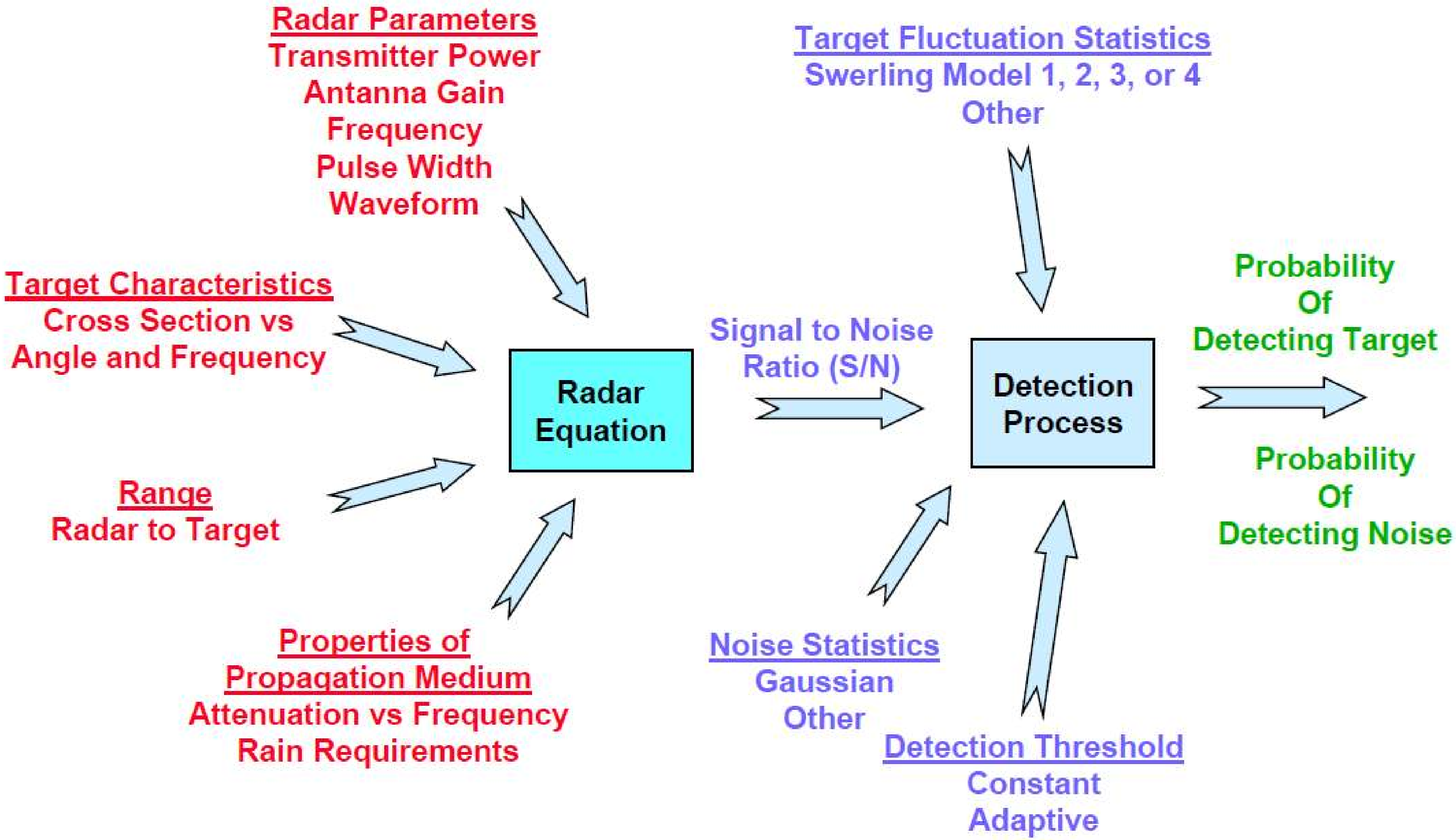
S / N = 1.3 dB per pulse (21 pulses integrated) => S / N per dwell = 14.5 dB
(+ 13.2 dB)

Cautions in Using the Radar Equation

- The radar equation is simple enough that everybody can learn to use it

- The radar equation is complicated enough that anybody can mess it up if you are not careful

Radar Equation and Detection Process



Q & A