Radar Systems and Radar Equation

1. What is A Radar?

2. Radar Use Cases

3. Radar Block Diagram

4. Radar Range Equation

5. Example of Radar Range Calculation

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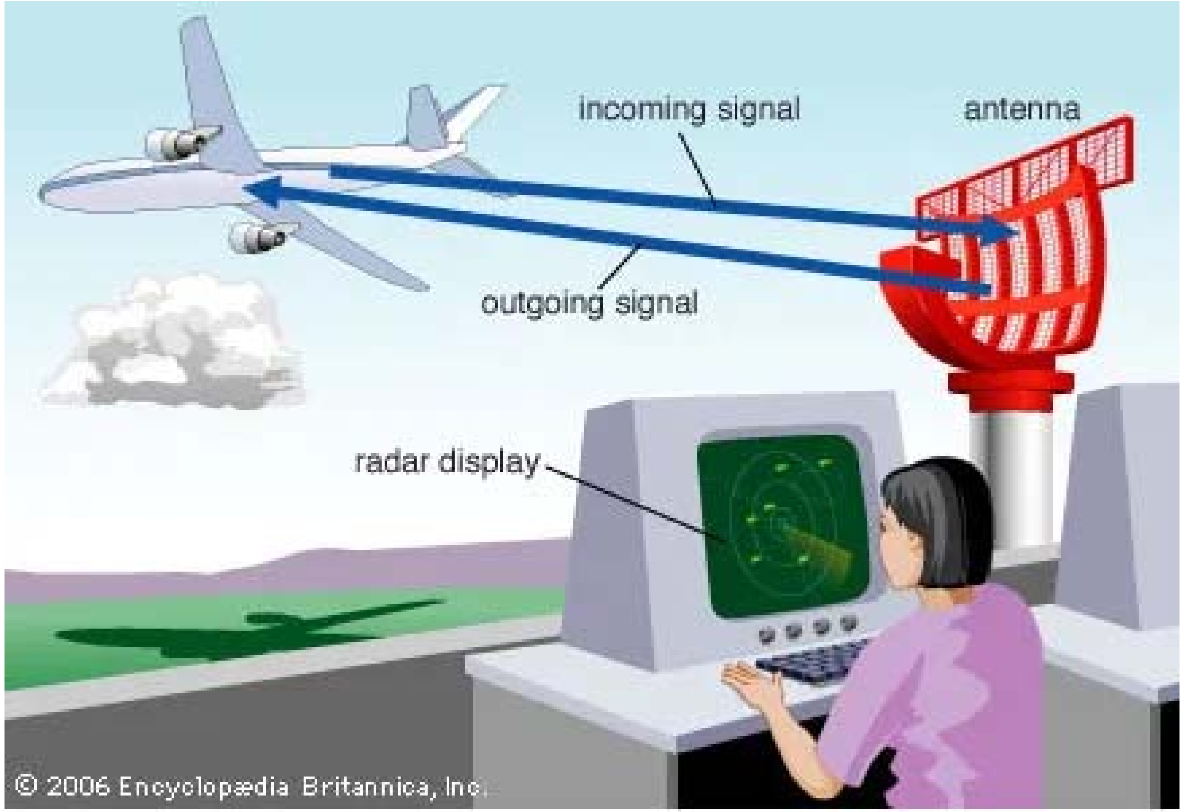
1. What is A Radar?

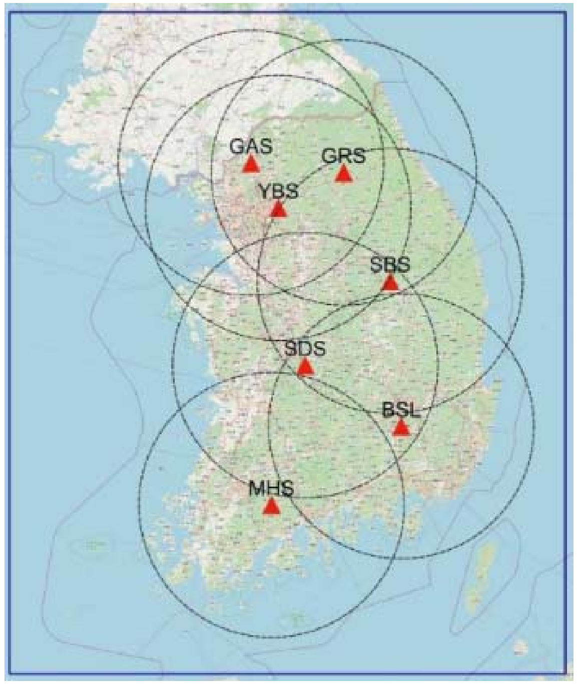
Radar (Radio Detection and Ranging)

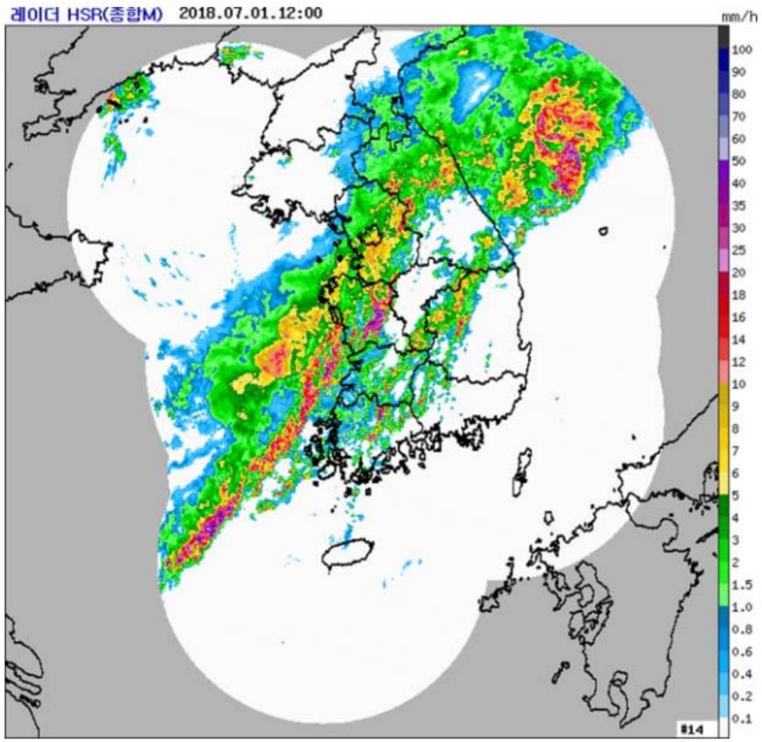
Example: Air-traffic contro radar



2. Radar Use Cases

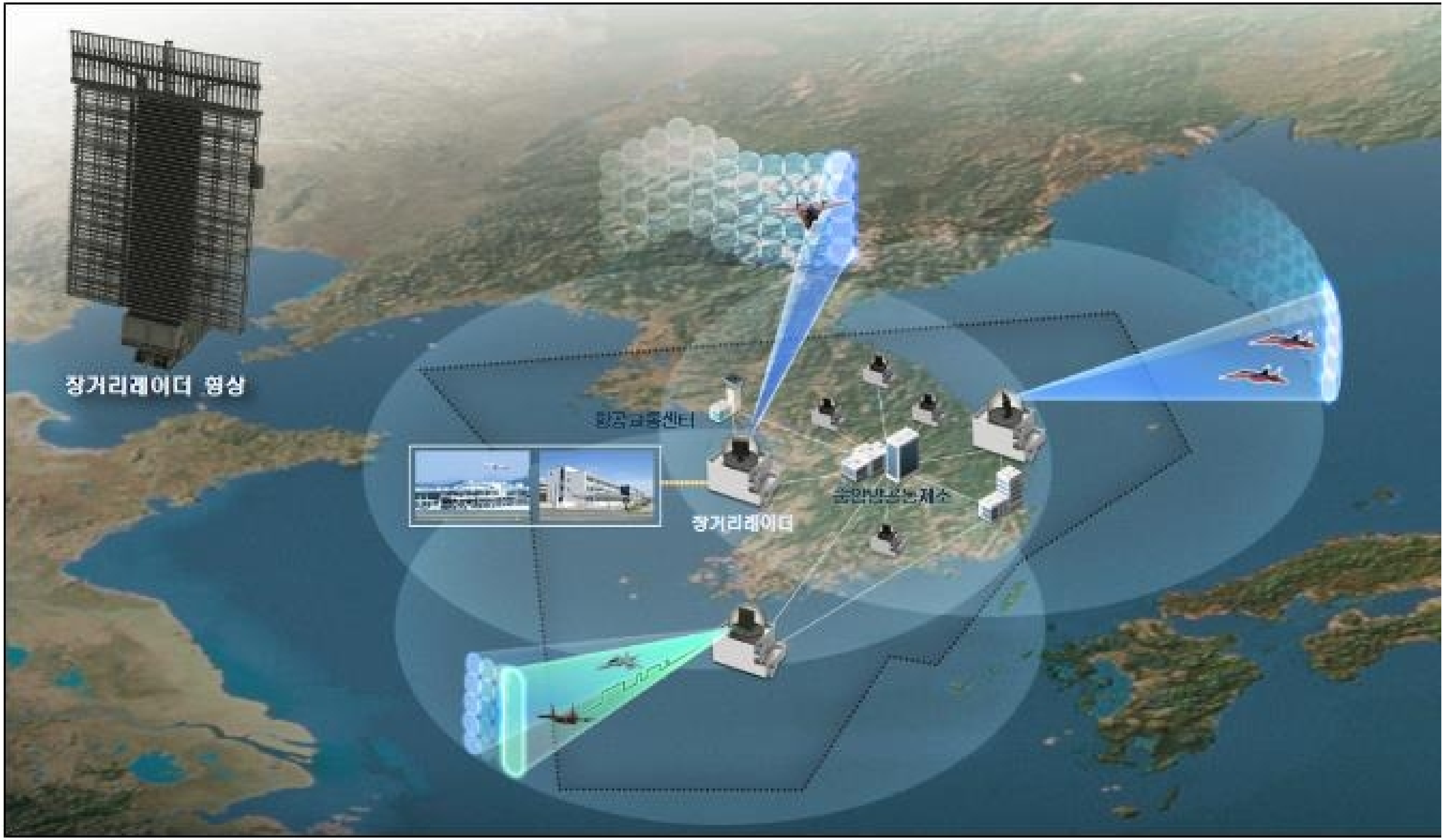
❑ Korea's S-band rain radar network



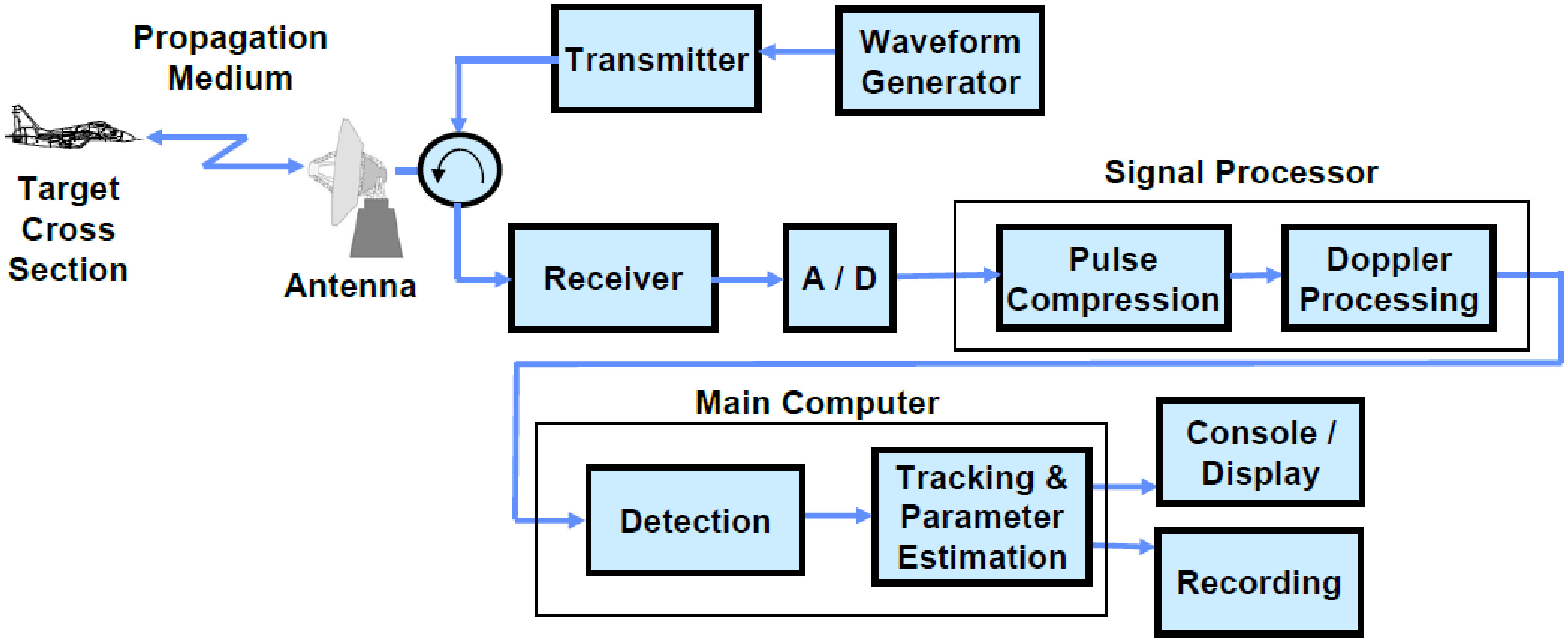


2. Radar Use Cases

- ❑ Air-surveillance radar for national defense



3. Radar Block Diagram



4. Radar Range Equation

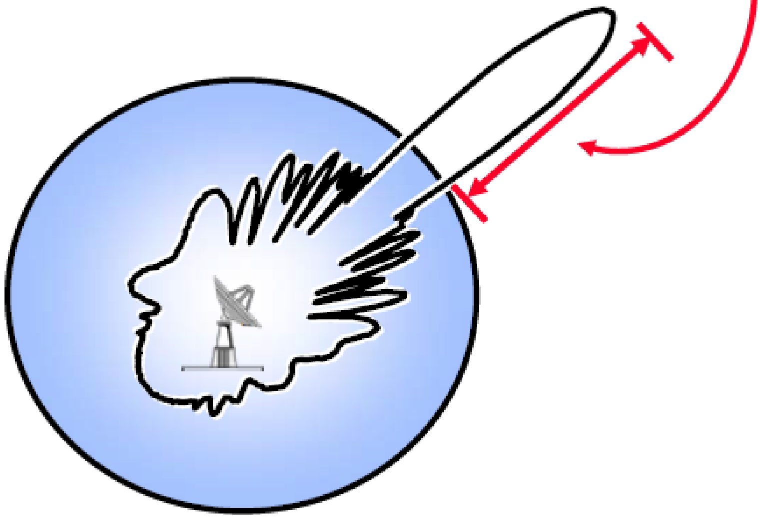
Power density from isotropic antenna $\dfrac{P_t}{4 \pi R^2}$

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

P_t = peak transmitter power

R = distance from radar

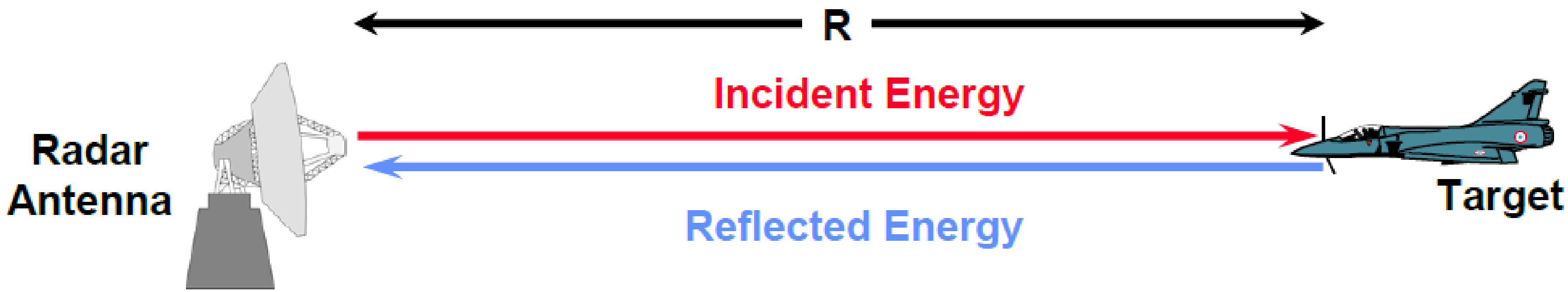
G_t = transmit gain



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

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

4. Radar Range Equation



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

σ = radar cross section units (meters)^2

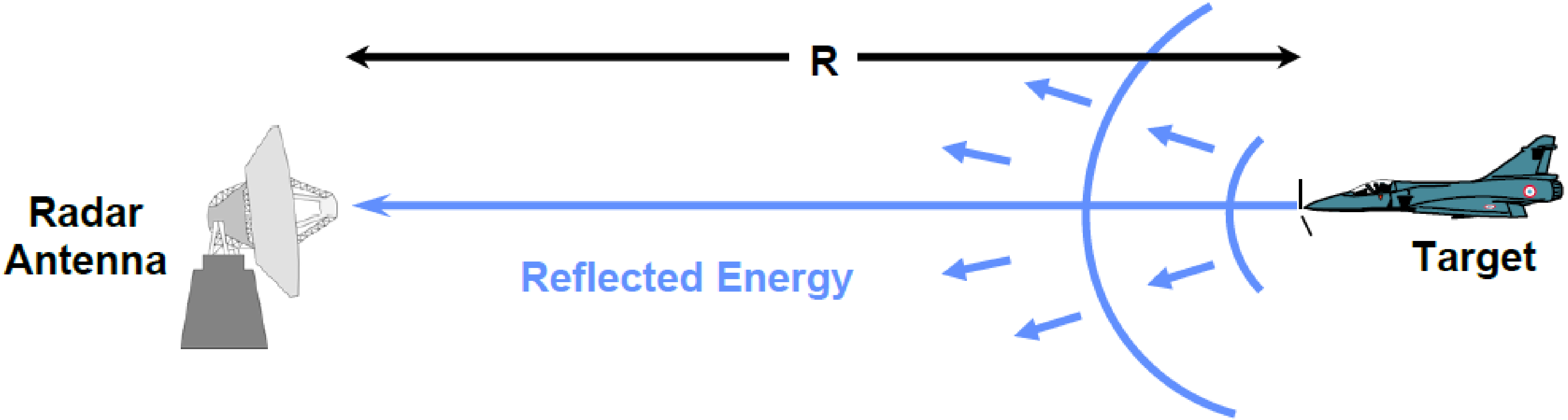
Power of reflected signal at target $\dfrac{P_t G_t \sigma}{4 \pi R^2}$

Power density of reflected signal at the radar $\dfrac{P_t G_t}{4 \pi R^2} \dfrac{\sigma}{4 \pi R^2}$

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

4. Radar Range Equation

Power density of reflected signal at radar $\quad \dfrac{P_t G_t}{4 \pi R^2} \; \dfrac{\sigma}{4 \pi R^2}$



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

4. Radar Range Equation

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

$$S / N = P_r / N$$

Assumptions :
$G_t = G_r$
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

4. Radar Range Equation

- 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

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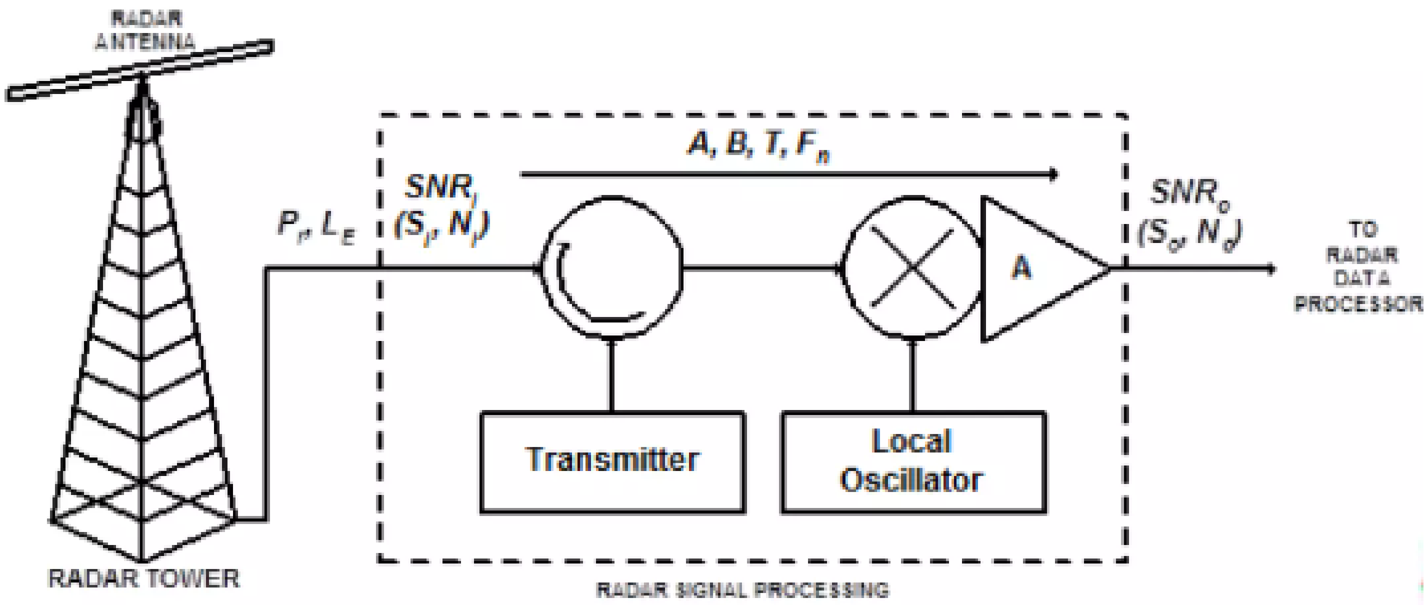
4. Radar Range Equation

- The output noise power,

$$N_o = AF_nN_i$$

since $N_i = kTB$

$$N_o = AF_nkTB$$



4. Radar Range Equation

- The signal to noise ratio at output,

$$SNR_o = \frac{S_o}{N_o} = \frac{A P_r / L}{A F_n kTB} = \frac{P_r}{F_n kTBL}$$

since

$$P_r = \frac{P_t G^2 \lambda^2}{(4\pi)^3 R^4} \sigma$$

the complete radar equation

$$SNR_o = \frac{P_t G^2 \lambda^2 \sigma}{(4\pi)^3 R^4 F_n kTBL}$$

T : Antenna noise temperature (K)

F_{n} : Receiver noise figure

$T_s = F_n T$: Radar receiving system noise temperature (K)

5. Example of Radar Range Calculation

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

Radar Parameters

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 $^\circ$
System Noise Temp.	950 $^\circ$ K

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

G = 4 π A / λ^2 = 15670 m^2
= 42 dB, (actually 33 dB with beam shaping losses)

Number of pulses per beamwidth = 21

Assume Losses = 8dB

5. Example of Radar Range Calculation

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

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

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

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

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

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)

6. Coding Problems

1. Write a Python code for the following problem.

Radar range calculation

(Input)

pt: radar pulse tx power (W); example =10e3

g: tx antenna (and rx antenna) gain (dB); example = 40

txL: tx side loss (dB); example = 2

snr: required signal to noise ratio; example = 16

rxL: rx side loss (dB); example = 2

ts: radara receiving system noise temperature (K); example = 1100

b: receiver bandwidth (Hz); example = 50e6

f: frequency (Hz); example = 2e9

sigma: target radar crosse section (m^2); example = 1

n: number of pulses integrated before detection; example = 20

(Output)

r: target detection range (m)

Fin

(End)