'*Blanket*'
FREE-SPACE RADAR RANGE

Conditions of Use, Disclaimer

This document contains scientific work. I cannot exclude, that the algorithm or the calculations contain errors and therefore expressly exclude any form of liability for damage which might arise from any possible use of this algorithm. The content of this document may be used only for private, non-commercial purposes.

Ingo Harre, Bremen, July 2001, Last Update: 2002-12-08   e-mail: Ingo.Harre@mar-it.de

Purpose of this Algorithm

This algorithm can be used to calculate the free-space range of a radar system. Free-space radar range is a theoretical performance figure rather than a range prediction for an actual system. It can be used, however, for comparing the performance of radar systems or their components (e.g. radar antennae). The calculus below is based on the reference book by Merrill I. Skolnik "Introduction to Radar Systems", Second Edition, McGraw-Hill Kogakusha INC and has been amended by the author.

1. Definition of Constants

Nautical mile $NM \equiv 1852 \cdot m$

Boltzmann's constant $k \equiv 1.380658 \cdot 10^{-23} \cdot W \cdot \frac{s}{K}$

Speed of light [m/s] $c \equiv 299792458 \cdot \frac{m}{s}$

System temperature $T_0 := 290 \cdot K$

2. Radar Transmitter / Receiver

Radar frequency [Hz] $f := 9.375 \cdot 10^{9} \cdot s^{-1}$

Wave length $\lambda := \frac{c}{f}$ $\lambda = 3.198\,cm$

Peak power transmitted [W] $P_p := 25 \cdot kW$

Pulse width [s] $\tau := 1 \cdot 10^{-6} \cdot s$

Pulse repetition frequency [Hz] $f_p := 1000 \cdot s^{-1}$

Average power $P_{avg} := P_p \cdot \tau \cdot f_p$ $P_{avg} = 25\,kg\,m^2\,s^{-3}$

Receiver band width [Hz] $B := 5 \cdot 10^6 \cdot s^{-1}$ $B = 5\,MHz$

Receiver noise figure [dB] $F_{dB} := 3.5$

Noise factor $F_n := 10^{\left(\frac{F_{dB}}{10}\right)}$ $F_n = 2.2$

System losses [dB] $L_{dB} := 4$

System losses $L_s := 10^{\left(\frac{L_{dB}}{10}\right)}$ $L_s = 2.5$

3. Radar antenna

If just the antenna width is known, insert it here; beamwidth and gain will be estimated. Otherwise, you can overwrite the gain and azimuthal beamwidth results calculated below by the actual figures of the antenna.

Antenna width [m] $a := 6.8 \cdot m$

Azimuthal beamwidth [deg] $\theta_h := \frac{83 \cdot \lambda}{a}$ $\theta_h = 0.39$

(Skolnik, table 7.1; applicable for cos² aperture distribution)

Vertical beam width [deg] $\theta_v := 15$ (if value not known, use 20° for slotted wave guide antennas)

Antenna power gain [db] $g := 10 \cdot \log\left[\frac{23750}{\left(\theta_h \cdot \theta_v\right)}\right]$ $g = 36.1$

(Skolnik, equation 7.8; constant adjusted by the author to fit with real-world antenas)

Antenna gain factor $G := 10^{\left(\frac{g}{10}\right)}$ $G = 4.1 \times 10^3$

Scan rate [rpm] $r_s := 24 \cdot min^{-1}$

Antenna height [m] $h_a := 30 \cdot m$

4. Target

Radar Cross Section [m²] $\sigma := 300 \cdot m^2$

The Radar Cross section of a target is frequency dependent. Make sure you use the correct value for the radar frequency chosen. If you have a value for a certain target that is valid for X band but you want to calculate the range for S band, the X band RCS should be reduced. As RCS not only depends on frequency but also on the shape of the target, you will find different adjustment factors in the literature. The author uses the following formula

$$\sigma_s := \frac{f_s}{f_x} \cdot \sigma_x$$

which reduces the X band RCS for the case mentioned above by approx. 5 dB for real targets. This reduction can be justified from the measurements of a naval vessel with both radar frequencies (Skolnik, Fig. 2.21).

Height [m] $h_t := 8 \cdot m$

The target height is normally the lower edge of the RCS area, so that the whole RCS area is visible above horizon.

5. General Parameters

The required signal/noise ratio will be calculated using the following two parameters:

False alarm probability $p_{fa} := 10^{-6}$ Exponent must be either -4 or -6.

Detection Probability $p_d := 0.9$ Range: 0.1 .... 0.9

Signal to noise ratio required for detection:

(Skolnik, Fig.2.7; approximation equations by the author)

$$sn_4 := 4.11031 + 32.21312 \cdot p_d - 67.02629 \cdot p_d^2 + 45.02943 \cdot p_d^3 \qquad sn_4 = 11.6$$

$$sn_6 := 6.67374 + 27.4839 \cdot p_d - 57.41762 \cdot p_d^2 + 38.62596 \cdot p_d^3 \qquad sn_6 = 13.1$$

$$SN_{dB} := \mathrm{wenn}\left(p_{fa} = 10^{-4}, sn_4, \mathrm{wenn}\left(p_{fa} = 10^{-6}, sn_6, 13\right)\right) \qquad SN_{dB} = 13.1$$

Signal to noise factor $SN := 10^{\left(\frac{SN_{dB}}{10}\right)}$ $SN = 20.2$

6. Range Calculation

The following equation is based on Skolnik equation 2.44 with P_{avg} substituted by P_p using equation 2.43 and $A_e\rho_a$ substituted by G using equation 7.9. The term $nE_i(n)$ has been discarded as post-detection integration is not considered here.

$$R_{fs1} := \left[\frac{P_p \cdot G^2 \cdot \sigma \cdot \lambda^2}{\left[(4\cdot\pi)^3 \cdot k \cdot T_0\right] \cdot B \cdot F_n \cdot SN \cdot L_s}\right]^{\left(\frac{1}{4}\right)}$$

free space range in km $R_{fs1} = 72.7\,\mathrm{km}$

free space range in NM $R_{fs1} = 39.3\,\mathrm{NM}$

7. Range calculation using logarithmic values (Decibels values)

$P_{dB} := 10 \cdot \log\left(\frac{P_p}{kW}\right)$ $\quad P_{dB} = 14$

$G_{dB} := 20 \cdot \log(G)$ $\quad G_{dB} = 72.2$

$\sigma_{dB} := 10 \cdot \log\left(\frac{\sigma}{m^2}\right)$ $\quad \sigma_{dB} = 24.8$

$\lambda_{dB} := 20 \cdot \log\left(\frac{\lambda}{m}\right)$ $\quad \lambda_{dB} = -29.9$

$K_{dB} := 10 \cdot \log\left[(4\cdot\pi)^3 \cdot \frac{k \cdot T_0}{W \cdot s}\right]$ $\quad K_{dB} = -171$

$B_{dB} := 10 \cdot \log\left(\frac{B}{kHz}\right)$ $\quad B_{dB} = 37$

$F_{dB} = 3.5$

$SN_{dB} = 13.1$

$L_{dB} = 4$

Figure of Merit:

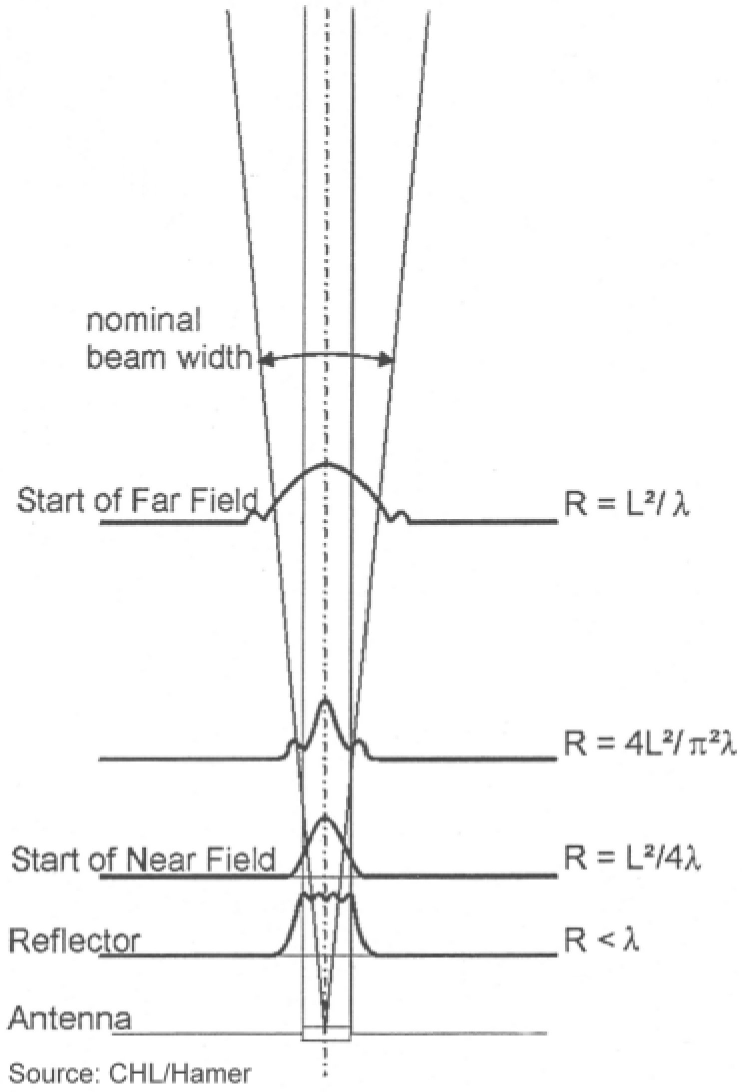
$$FM := P_{dB} + G_{dB} + \sigma_{dB} + \lambda_{dB} - K_{dB} - B_{dB} - F_{dB} - SN_{dB} - L_{dB}$$

$FM = 194.5$

$$R := \left[10^{\left(\frac{FM}{10}\right)}\right]^{\frac{1}{4}} \cdot m$$

$R = 72.7\,\mathrm{km}$ q.e.d

8. Antenna Parameters



(Skolnik, chapter 7.2)

Example:

Antenna Aperture

$a = 6.8\,m$

Fraunhofer Region

Main Lobe has characteristical form. Gain has reached 94% of max. gain. Area for precision radar measurement.

$$R_4 := \frac{a^2}{\lambda}$$

$$R_4 = 1.4 \times 10^3\,m$$

Fresnel Region

$$R_3 := \frac{4 \cdot a^2}{\pi^2 \cdot \lambda}$$

$$R_3 = 586\,m$$

Near Field Region

$$R_2 := \frac{a^2}{4 \cdot \lambda}$$

$$R_2 = 361.5\,m$$

$$R_1 := \lambda$$

$$R_1 = 0.032\,m$$