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17 APRIL 1970

NAFI publication

APPLIED RESEARCH DEPT.

RAPID CALCULATION TECHNIQUES FOR RADAR PERFORMANCE PREDICTIONS

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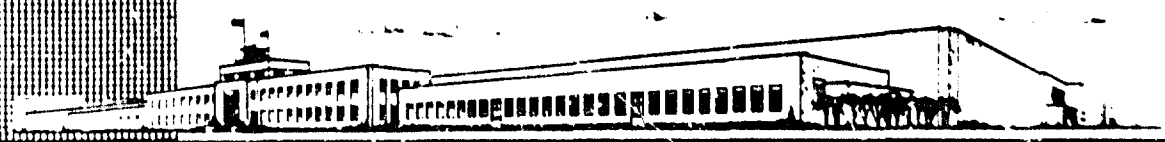

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ABSTRACT

This report provides a work form and rationale to perform hand calculations of the radar range equation. The techniques described cover the conventional geometric aspects of the radar equations as well as the effects of rain clutter, rain attenuation, atmospheric attenuation, sea and land clutter, and pulse integration for both conventional pulse and chirp radar. The report is designed to be complete within itself, requiring no further texts, tables, references or slide rules.

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TABLE OF CONTENTS

I. INTRODUCTION 1

II. CALCULATIONS 3

A. Maximum Range Estimation 3
B. Calculation of Signal to Noise Plus Clutter. 6

APPENDIX A: SIMPLIFIED RADAR DATA A-1

APPENDIX B: MATHEMATICAL DERIVATION. B-1

APPENDIX C: WORK FORM USAGE EXAMPLE C-1

I. INTRODUCTION

In the evaluation of the detection performance of a radar system, it is necessary to use the radar equation in one of its many forms. Unfortunately the mixture of units and the calculation of clutter effects defy convenient manipulation. However, with certain simplifying assumptions and limitations, one can develop equations which can be used conveniently by hand. The calculation techniques in this report cover the effects of rain clutter, rain attenuation, atmospheric attenuation, sea clutter, land clutter and pulse integration as well as the conventional geometric aspects.

The limiting assumptions are: the depression (or elevation) angle must be less than 10°, the slant range must be greater than 3 nautical miles, and the radar and target altitude should be less than 10,000 feet. These limits are imposed by certain geometric simplifications. Fortunately, the majority of radar applications fall well within these limitations.

The goal of this report is to allow an evaluation to be made without further reference to any aids, including charts, tables or slide rule. These techniques were originally developed at NAFI in order to more fully assess a radar design during meetings and conferences.

Other, more general techniques, as well as a more complete discussion of many of the parameters and their effect on a radar system can be found in the following NAFI reports: "Simplified Radar Calculation Techniques" NAFI TR-917, and "Computer Aided Radar Design" NAFI TR-1461.

Most of the calculations in this report use decibels to facilitate division, multiplication and root extractions. Numerous simplified tables are included to estimate integration, attenuation and clutter effects. The major radar parameters calculated include maximum range, integrated signal to noise, signal to weather clutter, signal to land clutter and signal to sea clutter ratio. These ratios may be combined to yield the integrated signal to noise plus weather plus sea or land clutter ratio for any specified range and target.

The calculation of the integrated signal to noise plus clutter ratio is performed in two parts. The first part uses Section A to determine an estimate of the maximum range without any clutter or weather effects. The second part uses Section B to calculate the integrated signal to noise plus clutter ratio with clutter and weather effects at a particular range. Most calculations are in decibels and a foldout decibel to ratio conversion table is given in Appendix A to help the user. Section A and section B are work forms for calculation of maximum range and signal to noise plus clutter ratio, respectively.

Appendix B presents the mathematical derivation of the simplified equations used in sections A and B. Appendix C is an example of the usage of the work forms.

II. CALCULATIONS

A. MAXIMUM RANGE ESTIMATION

1. Single Pulse

Parameter	Value	Units	db Representation	Multiply By	Add db Results
P_k : Peak Power		KW		+1	
λ : Wavelength		cm		+2	
σ_T : Target RCS		M^2		+1	
G : Antenna Gain		db		+2	
L : Losses		db		-1	
B : Bandwidth		MHz		-1	
$\overline{NF}_o$: Noise Figure		db		-1	
(S/N): Signal/Noise		db		-1	
Conversion Factor					-30

4 db nautical miles = SUM_{4R} = _____ db

The maximum range (N miles) is obtained by multiplying the SUM_{4R} decibel by $\frac{1}{4}$ and expressing this as a ratio:

Maximum Range Estimation = _____ NM

2. Comments

a. Chirp Systems

(1). Use peak transmitter power (as at the antenna)

(2). Use the narrow, unchirped bandwidth

b. Antenna Gain

(1). If aperture only is given, see table in Appendix A.

c. Losses

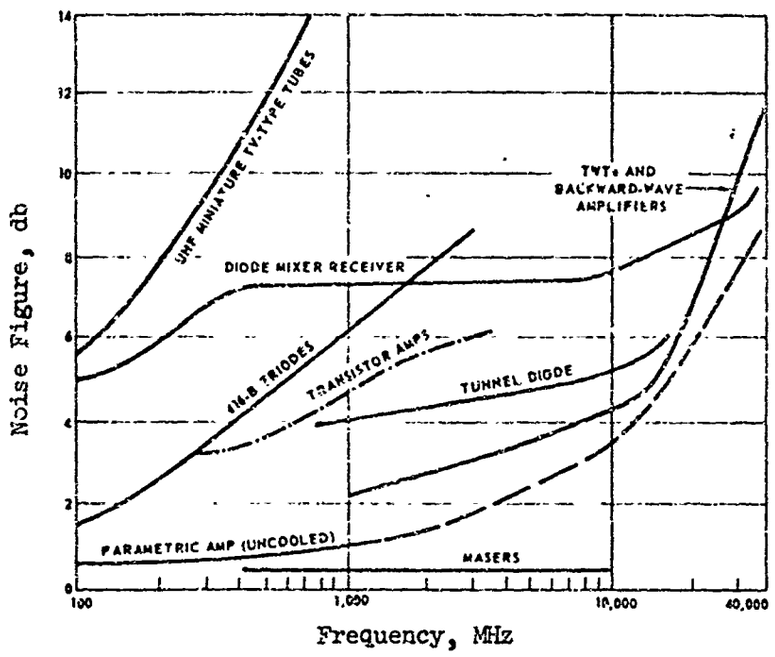
(1). Typical value for search radar 16 db, minimum value 10 db.

(2). Losses included are:

		Minimum db
L_c	collapsing	2
L_i	integration	1
L_e	gate or filter overlap	0
L_g	threshold	1
L_d	scan distribution	1
L_f	target	0
L_n	antenna efficiency	0
L_m	filter matching	1
L_o	post detection integration	1
L_p	antenna pattern	1
L_r	receiving loss	1
L_t	transmitting loss	1
L_s	scanning loss	0
		10 db

d. Signal to Noise Ratio (S/N). Typical value: 12db. This provides a probability of detection of about 90 percent with a false alarm ratio of .0001. For other values see Appendix A.

e. Noise Figure. The following table gives the minimum noise figures that may be expected from different types of detectors. Actual values that may be expected from equipment in the field exceed these values by about 40 percent.



f. PRF Limited Range

Parameter	Value	Units	db Representation	Multiply By	Add db Results
PRF		pulses/sec		-1	
Conversion Factor				→	+49.2db

U_{db}, Unambiguous decibel range = _____ db

The PRF limited range is the ratio representation of the Unambiguous decibel range, U_{db}. Therefore, PRF Limited Range = _____ NM

B. CALCULATION OF $\left(\frac{S}{N + C_{\omega} + C_{S/L}}\right)_i$ RATIO

1. Preliminary Information for $\left(\frac{S}{N + C_{\omega} + C_{S/L}}\right)_i$ Calculation

Limitations: Radar height less than 10,000 feet.

Target height less than 10,000 feet.

Depression angles less than 10 degrees.

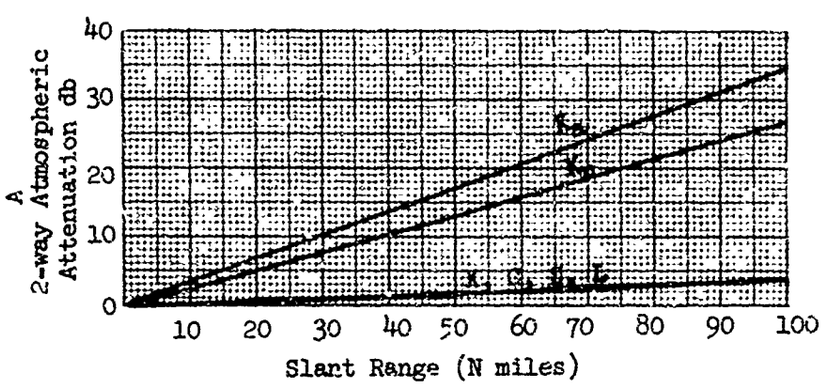
Slant ranges greater than 3 N miles

a. Slant Range, R = _____ n miles

Radar Height, h = _____ (100's feet)

Depression angle, θ°, = $\frac{h \text{ (100's ft)}}{R \text{ (n miles)}}$ = _____ degrees.

b. Atmospheric Attenuation, A = _____ db.



c. Rain Attenuation

(1)

Parameter	Value	Units	db Representation	Multiply By	Add db Results
R : Range		NM		+1	
W : Rain Rate		mm/hr		+1	
λ : Wavelength		cm		-2	
Factor					-1.42

SUM_R = _____ db

(2)

Parameter	Value	Units	Ratio Representation	A_R
SUM_R		db		

A_R, 2-way Rain Attenuation = _____ db

2. Calculation of (S/N)i

a. Single Pulse $(S/N)_1$

Parameter	Value	Units	db Representation	Multiply By	Add db Results
P_k : Peak Power		Kw		+1	
λ : Wavelength		cm		+2	
σ_T : Target RCS		M^2		+1	
G : Antenna Gain		db	→	+2	
L : Losses		db	→	-1	
A : Atmospheric Attenuation		db	→	-1	
A_R : Rain Attenuation		db	→	-1	
NF_o : Noise Figure		db	→	-1	
B : IF Bandwidth		MHz		-1	
R : Range		NM		-4	
Factor				→	-30.0

$(\frac{S}{N})_1$ = _____ db

b. Integration Improvement (Assuming visual PPI detection)

PRF = _____ pulses/second

AZ° = _____ degrees

SCAN RATE _____ degrees/second

number of Hits/Scan, #H = $\frac{(PRF)(AZ°)}{(SCAN\ RATE)}$ = _____ Hits/Scan

#H, (Hits/Scan) =	5	10	15	20	25	30	40	50	60
I, Integration Improvement in db =	6	8.4	9.6	10.5	11.2	11.8	12.6	13.2	13.8

Integration Improvement, I = _____ db

c. Integrated $(S/N)_i$

$$(\frac{S}{N})_i = (\frac{S}{N})_1 (db) + I db = _____ db$$

3. Calculation of $\left(\frac{S}{C_\omega}\right)_i$

a. Single Pulse $(S/C_\omega)_1$

Parameter	Value	Units	db Representation	Multiply By	Add db Results
σ_T : Target RCS		M^2		+1	
λ : Wavelength		cm		+4	
W : Rain Rate		mm/hr		-1.6	
AZ : AZ Beamwidth		deg.		-1	
EL : EL Beamwidth		deg.		-1	
τ : Pulse Length		μ sec		-1	
R : Range		NM		-2	
Factor					+ 4.87 db

$(S/C_\omega)_1 =$ _____ db

b. Integration Factor

Integration Improvement, I, from 2b. = _____ db

c. Pulse Compression Ratio

Pulse Compression Ratio = _____ unitless

The Pulse Compression Factor, CR, is the decibel representation of the unitless Pulse Compression Ratio.

Therefore, Pulse Compression Factor, CR = _____ db

d. Integrated $(S/C_\omega)_i$

$$\left(\frac{S}{C_\omega}\right)_i = \left(\frac{S}{C_\omega}\right)_{1db} + I_{db} + CR_{db} = _____ \text{ db}$$

4. Calculate $\left(\frac{S}{C_{S/L}}\right)_i$

a. Clutter Reflectivity

(1). Depression Angle, θ, from 1a. = _____ deg.

Radar Band = _____

Clutter Type = _____

Clutter Reflectivity, σ_c, from Clutter values Appendix A. = _____ db.

(2). Pulse Compression Effect:

Parameter	Value	Units	Multiply By	Add db Results
σ_o : Clutter Reflectivity		+db	-1	
CR : From Sec. 3c.		+db	-1	

σ_o(EFF), Effective Clutter Reflectivity = _____ db.

b. Single Pulse $\left(\frac{S}{C_{S/L}}\right)_1$

Parameter	Value	Units	db Representation	Multiply by	Add db Results
σ_T : Target RCS		M^2		+1	
τ : Pulse Length		μsec		-1	
R : Range		NM		-1	
AZ : AZ Beamwidth		deg.		-1	
σ_o(EFF): From Sec. 4a.		db		-1	
Factor					-35.35 db

Single Pulse $\left(\frac{S}{C_{S/L}}\right)_1$ = _____ db

c. Integrated $\left(\frac{S}{C_{S/L}}\right)_i$

$\left(\frac{S}{C_{S/L}}\right)_1$ (from Sec. 4b.) = _____ db

I (From Sec. 2b.) = _____ db

$\left(\frac{S}{C_{S/L}}\right)_i = \left(\frac{S}{C_{S/L}}\right)_1 + I =$ _____ db

5. Calculate $\left(\frac{S}{N + C_\omega + C_{S/L}}\right)_i$

a. Calculate "Energy" Ratio

Parameter	Value	Units	Multiply By	Add Ratio Representation
$(S/N)_i$: Section 2c.		db	-1	
$(S/C_\omega)_i$: Section 3d.		db	-1	
$(S/C_{S/L})_i$: Section 4c.		db	-1	

E, Inverse "Energy" Ratio = _____ unitless

b. Integrated $\left(\frac{S}{N + C_\omega + C_{S/L}}\right)_i$

Parameter	Value	Units	db Representation	Multiply By	$\left(\frac{S}{N+C_\omega+C_{S/L}}\right)_i$ db
E, Sec. 5a.		unitless		-1	

$\left(\frac{S}{N + C_\omega + C_{S/L}}\right)_i$ = _____ db

APPENDIX A

SIMPLIFIED RADAR DATA

A. Signal to Noise Ratio VS Probability of Detection

$\left(\frac{S}{N + C_{\omega} + C_{S/L}}\right)_i$	Probability of Detection	Probability of False Alarm
4 db	99 %	
	90	.50
	80	.25
	50	.05
8 db	99	.30
	90	.05
	80	.02
	50	.01
12db	99	5×10^{-2}
	90	10^{-4}
	80	10^{-5}
	50	10^{-7}
16 db	99.9	10^{-7}
	99	10^{-10}
	90	10^{-13}
	80	10^{-14}

B. Clutter Reflectivity: σ_o in db below one square meter

Ka Band 35 GHz						Ku Band 17 GHz					
Clutter	Grazing Angle .1°	.3°	1°	3°	10°	Clutter	Grazing Angle .1°	.3°	1°	3°	10°
Seastate 1			43	41	38	Seastate 1			47	43	40
3			34	34	31	3			37	36	32
5			31	30	26	5		39	32	31	26
Desert					22	Desert					26
Farm Land				23	20	Farm Land			23		23
Wooded				13	19	Wooded			20		20
City						City					

X Band 10 GHz						C Band 5.6 GHz					
Clutter	Grazing Angle .1°	.3°	1°	3°	10°	Clutter	Grazing Angle .1°	.3°	1°	3°	10°
Seastate 1	65	58	50	45	42	Seastate 1	75	60	53	49	44
3	51	45	39	38	32	3	56	48	43	40	34
5	44	39	33	31	26	5	48	41	35	33	28
Desert			38		26	Desert					
Farmland			36		25	Farmland			38		29
Wooded			30		23	Wooded			35		
City			24		12	City					

S Band 36 GHz						L Band 1.25 GHz					
Clutter	Grazing Angle .1°	.3°	1°	3°	10°	Clutter	Grazing Angle .1°	.3°	1°	3°	10°
Seastate 1	80	62	56	52		Seastate 1			65	53	54
3	68	55	48	43	34	3	82		54	43	34
5	53	50	38	35	28	5	65		43	38	28
Desert				30	28	Desert				45	40
Farmland					21	Farmland				32	33
Wooded				33	25	Wooded				34	23
City					18	City				30	18

C. ANTENNA CHARACTERISTICS

1. Beamwidth Calculations

a. Azimuth Beamwidth

Parameter	Value	Unit	db Representation	Multiply By	Add db Results
Wavelength		cm		+1	
Antenna Width		ft		-1	
Conversion Factor	→			→	+4.3 db

Decibel Antenna Beamwidth, AZ_{db} = _____ db

b. Elevation Beamwidth

Parameter	Value	Unit	db Representation	Multiply By	Add db Results
Wavelength		cm		+1	
Antenna Height		ft		-1	
Converstion Factor	→			→	+4.3 db

Decibel Antenna Beamwidth, EL_{db} = _____ db

The antenna beamwidths in degrees are the ratio representation of the decibel antenna beamwidth. Therefore,

AZ° = _____ degrees

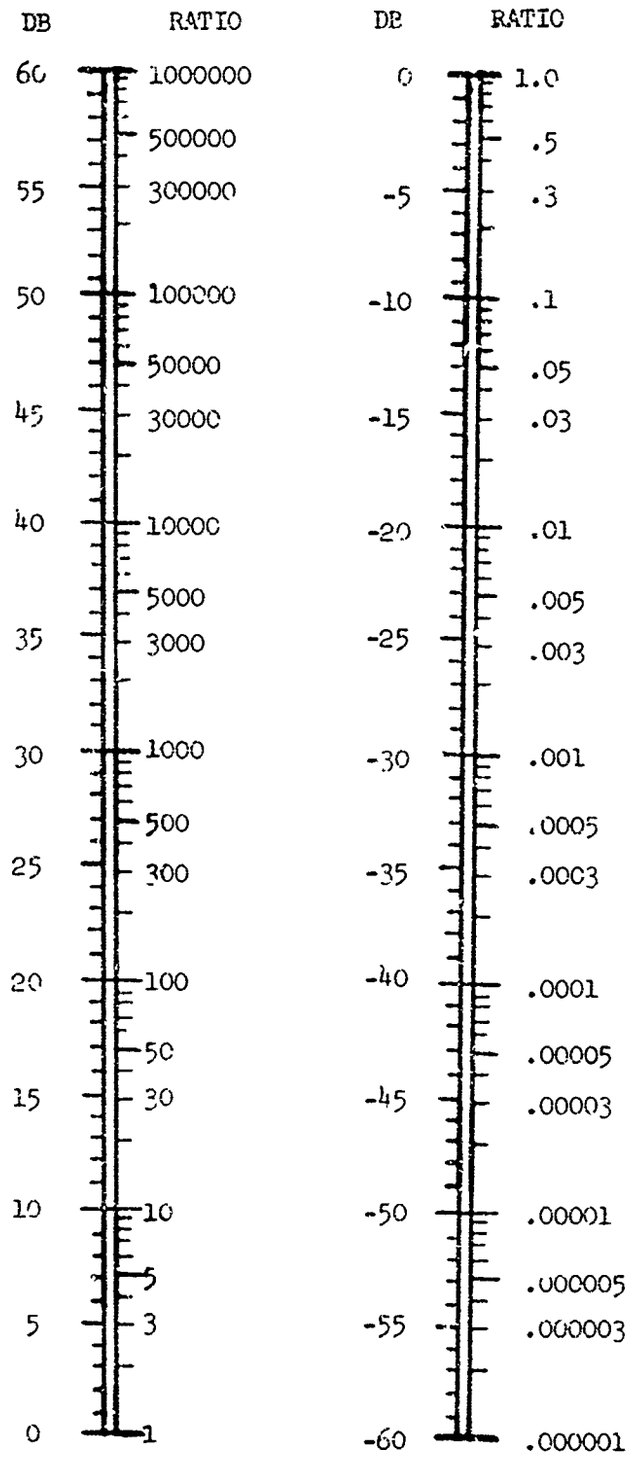
EL° = _____ degrees

2. Antenna Gain Calculation

Parameter	Value	Units	db Representation	Multiply By	Add db Results
AZ°		deg.		-1	
EL°		deg.		-1	
Conversion Factor	→			→	+44.3db

Antenna Gain, G = _____ db

D. DECIBEL TO RATIO CONVERSION TABLE


DB
RATIO
DB
RATIO
60
1000000
0
1.0
500000
.5
55
300000
-5
.3
50
100000
-10
.1
50000
.05
45
30000
-15
.03
40
10000
-20
.01
5000
.005
35
3000
-25
.003
30
1000
-30
.001
500
.0005
25
300
-35
.0003
20
100
-40
.0001
50
.00005
15
30
-45
.00003
10
10
-50
.00001
5
.000005
5
3
-55
.000003
0
1
-60
.000001

B

APPENDIX B

SIMPLIFIED MATHEMATICAL DERIVATION FOR $\left(\frac{S}{N + C_{\omega} + C_{S/L}}\right)_i$

The derivation of the equations used in this report are in NAFI TR-1461. The decibel equation form used is as given in NAFI TR-917. The following derivations are a summary of some of the equations in these two reports.

A. SINGLE PULSE SIGNAL TO NOISE RATIO

$$\left(\frac{S}{N}\right)_i = \left(\frac{P\lambda^2}{BR^4}\right) \sigma_T \, 10^{(2G - L - A_R - \overline{NF}_o)/10} \times 10^3 \qquad \text{(B.1)}$$

where

S = Signal Power Watts
N = Noise Power Watts
P = Peak Power, kw
λ = Wavelength, cm
σ_T = Target RCS, M^2
B = IF Noise Bandwidth, MHz
R = Slant Range, NM
G = Antenna Gain, db
L = System Losses, db
A_R = Rain Losses, db
A = Atmospheric Attenuation, db
$\overline{NF}_o$ = Noise Figure, db

B. WEATHER CLUTTER BACKSCATTER

$$\sigma_{\omega} = \frac{W^{1.6} \, AZ^{\circ} \, EL^{\circ} \, R^2 \, \tau}{\lambda^4} \, .32549 \, (M^2)$$

$$\left(\frac{C_\omega}{N}\right)_1 = \left(\frac{S}{N}\right)_1 \frac{\sigma_\omega}{\sigma_T}$$

therefore

$$\left(\frac{S}{C_\omega}\right)_1 = \frac{\sigma_T}{\sigma_\omega}$$

Therefore, signal to weather clutter ratio:

$$\left(\frac{S}{C_\omega}\right)_1 = \frac{\sigma_T \quad \lambda^4 \quad 3.072}{W^{1.6} \; AZ^\circ \; EL^\circ \; R^2 \; \tau} \qquad \text{(B.2)}$$

where:

C_ω = Weather clutter backscatter power, watts
σ_ω = Weather clutter reflective area, M^2
W = Rain Rate, MM/Hour
AZ° = Antenna azimuth beamwidth, degrees
EL° = Antenna elevation beamwidth, degrees
τ = Pulse length, μ seconds

C. SEA OR LAND CLUTTER RETURN

$$\sigma_{S/L} = \frac{AZ^\circ \; R \; \tau}{\cos E} \; 3427.1 \; 10^{(\sigma_o/10)} \; (M^2)$$

Assume: pulse width limited clutter

Assume: depression angle, E, is less than 10° so Cos E = 1

Therefore,

$$\sigma_{S/L} = AZ^\circ \; R \; \tau \; 10^{(\sigma_o/10)} \quad 3427.1 \; M^2$$

$$\left(\frac{S}{C_{S/L}}\right) = \frac{\sigma_T}{\sigma_{S/L}}$$

$$\left(\frac{S}{C_{S/L}}\right) = \frac{\sigma_T \quad 2.917 \times 10^{-4}}{AZ^\circ \; R \; \tau \; 10^{(\sigma_o/10)}} \qquad (B.3)$$

where

$\sigma_{S/L}$ = Sea or land clutter area, M^2

σ_o = Clutter reflectivity, db_{M^2}

E = Depression angle, degrees

$C_{S/L}$ = Sea or land clutter return, watts

D. INTEGRATED $\left(\frac{S}{N + C_\omega + C_{S/L}}\right)_i$ RATIO

$$\left(\frac{S}{N + C_\omega + C_{S/L}}\right)_i \equiv 10 \log \left(\frac{S}{N + C_\omega + C_{S/L}}\right) + I(\text{in db})$$

where: I = Integration Improvement, db

Let: I_F = Integration Improvement Ratio = $10^{(I/10)}$, unitless

Derivation: Using Equations (B.1), (B.2) and (B.3), the integrated signal to noise plus weather clutter plus sea or land clutter ratio may be written as:

$$\frac{S}{N + C_\omega + C_{S/L}} = \frac{1}{\frac{N}{S} + \frac{C_\omega}{S} + \frac{C_{S/L}}{S}}$$

$$\frac{S}{N + C_\omega + C_{S/L}} = \frac{1}{\frac{1}{\left(\frac{S}{N}\right)} + \frac{1}{\left(\frac{S}{C_\omega}\right)} + \frac{1}{\left(\frac{S}{C_{S/L}}\right)}}$$

The equation as used in this report is:

$$\left(\frac{S}{N + C_\omega + C_{S/L}}\right)_j = 10 \log \left[\frac{1}{\frac{1}{\left(\frac{S \cdot I_F}{N}\right)} + \frac{1}{\left(\frac{S \cdot I_F}{C_\omega}\right)} + \frac{1}{\left(\frac{S \cdot I_F}{C_{S/L}}\right)}}\right]$$

E. DEPRESSION ANGLE APPROXIMATION

R = Slant Range, N miles

h = Height, 100's feet

E° = Depression Angle, degrees

therefore

$$R \sin E^\circ = \frac{h}{60.8}$$

let $\sin E^\circ = E_{(Rad.)}$

therefore

$$E_{(Rad)} = \frac{h}{R \quad 60.8} \text{ (Rad)}$$

$$E_{(deg)} = E^c = \frac{h}{R \quad 60.8} \quad \frac{360^\circ}{2\pi \text{ Rad}}$$

$$E^\circ = \frac{h}{R} \cdot 942$$

therefore

$$E^\circ \approx \frac{h(100\text{'s feet})}{R(N \text{ miles})} \text{ in degrees}$$

APPENDIX C

WORK FORM USAGE EXAMPLE

This is an example of usage of the work forms presented in sections A and B. The calculations are for the performance of a radar which has the following characteristics.

RADAR PARAMETERS

P:	50 kw
L:	13 db
$\overline{NF}_o$:	10 db
λ:	3.22 cm (X band)
Rain:	1mm/hour
Antenna:	AZ = 2°, EL = 2°, Gain = 38 db
τ:	1 μsec
B:	1 MHz
PRF:	1000 pulses/sec
Scan Rate:	90°/sec
Target RCS:	1000 M^2
Radar Height:	6,000 feet
Target Height:	0 feet
Clutter:	sea state 3
Desired Pd:	90% at PFA = 10^{-4}

II. CALCULATIONS

A. MAXIMUM RANGE ESTIMATION

1. Single Pulse

Parameter	Value	Units	db Representation	Multiply By	Add db Results
P_k : Peak Power	50	KW	17 db	+1	+17db
λ : Wavelength	3.22	cm	5.1db	+2	+10.2db
σ_T : Target RCS	1000	M^2	30db	+1	+30db
G : Antenna Gain	38	db	→	+2	+76db
L : Losses	13	db	→	-1	-13db
B : Bandwidth	1	MHz	0 db	-1	-0db
$\overline{NF}_o$: Noise Figure	10	db	→	-1	-10db
(S/N): Signal/Noise	16	db	→	-1	-16db
Conversion Factor			→		-30

4 db nautical miles = SUM_{4R} = 64.2 db

The maximum range (N miles) is obtained by multiplying the SUM_{4R} decibel by $\frac{1}{4}$ and expressing this as a ratio:

Maximum Range Estimation = 40 NM

2. Comments

a. Chirp Systems

(1). Use peak transmitter power (as at the antenna)

(2). Use the narrow, unchirped bandwidth

b. Antenna Gain

(1). If aperture only is given, see table in Appendix A.

c. Losses

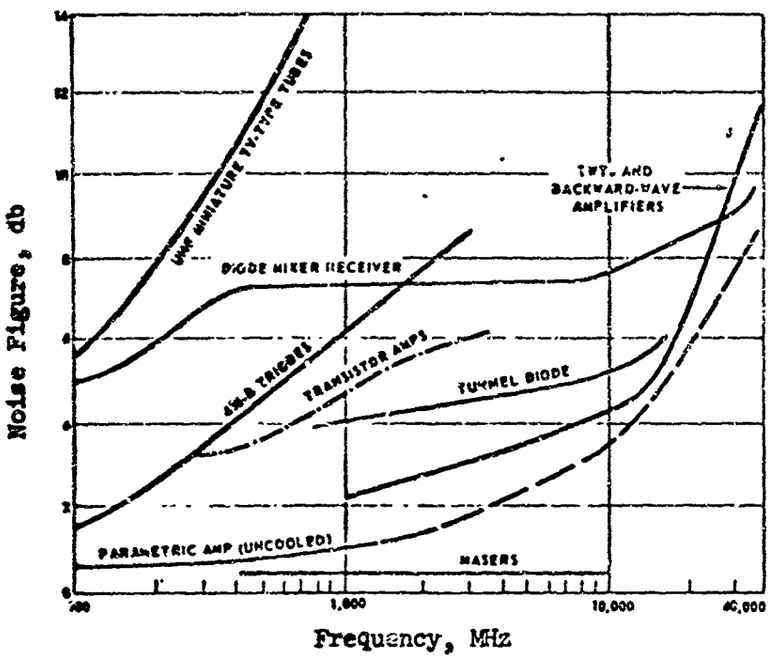
(1). Typical value for search radar 16 db, minimum value 10 db.

(2). Losses included are:

		Minimum db
L_c	collapsing	2
L_i	integration	1
L_e	gate or filter overlap	0
L_g	threshold	1
L_d	scan distribution	1
L_r	target	0
L_n	antenna efficiency	0
L_m	filter matching	1
L_o	post detection integration	1
L_p	antenna pattern	1
L_r	receiving loss	1
L_t	transmitting loss	1
L_s	scanning loss	0
		10 db

d. Signal to Noise Ratio (S/N). Typical value: 12db. This provides a probability of detection of about 90 percent with a false alarm ratio of .0001. For other values see Appendix A.

e. **Noise Figure.** The following table gives the minimum noise figures that may be expected from different types of detectors. Actual values that may be expected from equipment in the field exceed these values by about 40 percent.



f. PRF Limited Range

Parameter	Value	Units	db Representation	Multiply By	Add db Results
PRF	1500	pulses/sec	31.5 db	-1	-31.5db
Conversion Factor				→	+49.2db

U_{db}, Unambiguous decibel range = +17.7 db

The PRF limited range is the ratio representation of the Unambiguous decibel range, U_{db}. Therefore, PRF Limited Range = 60 NM

B. CALCULATION OF $\left(\frac{S}{N + C_\omega + C_{S/L}}\right)_i$ RATIO

1. Preliminary Information for $\left(\frac{S}{N + C_\omega + C_{S/L}}\right)_i$ Calculation

Limitations: Radar height less than 10,000 feet.

Target height less than 10,000 feet.

Depression angles less than 10 degrees.

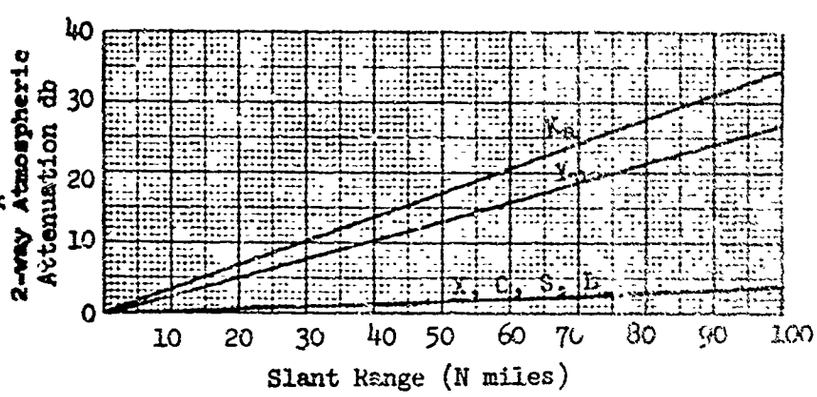
Slant ranges greater than 3 N miles

a. Slant Range, R = 40 n miles

Radar Height, h = 60 (100's feet)

Depression angle, θ°, = $\frac{h\ (100\text{'s ft})}{R\ (\text{n miles})}$ = 1.5 degrees.

b. Atmospheric Attenuation, A = 1.0 db.



c. Rain Attenuation

(1)

Parameter	Value	Units	db Representation	Multiply By	Add db Results
R : Range	40	NM	16 db	+1	+16 db
W : Rain Rate	1	mm/hr	0 db	+1	0 db
λ : Wavelength	3.22	cm	5.1 db	-2	-10.2 db
Factor					-1.42

SUM_R = 4.4 db

(2)

Parameter	Value	Units	Ratio Representation	A_R
SUM_R	4.4	db	2.8	2.8

A_R, 2-way Rain Attenuation = 2.8 db

2. Calculation of (S/N)i

a. Single Pulse $(S/N)_1$

Parameter		Value	Units	db Representation	Multiply By	Add db Results
P_k	: Peak Power	50	Kw	17 db	+1	+17 db
λ	: Wavelength	3.22	cm	5.1 db	+2	+10.2 db
σ_T	: Target RCS	1000	M^2	30 db	+1	+30 db
G	: Antenna Gain	38	db	→	+2	+76 db
L	: Losses	13	db	→	-1	-13 db
A	: Atmospheric Attenuation	1	db	→	-1	-1 db
A_R	: Rain Attenuation	2.8	db	→	-1	-2.8 db
$\overline{NF}_o$	: Noise Figure	10	db	→	-1	-10 db
B	: IF Bandwidth	1	MHz	0 db	-1	-0 db
R	: Range	40	NM	16 db	-4	-64 db
	Factor				→	-30.0 db

$(\frac{S}{N})_1$ = 12.4 db

b. Integration Improvement (Assuming visual PPI detection)

PRF = 1500 pulses/second

AZ° = 2 degrees

SCAN RATE 90 degrees/second

number of Hits/Scan, $\#H = \frac{(PRF)(AZ°)}{(SCAN\ RATE)}$ = 33 Hits/Scan

#H, (Hits/Scan) =	5	10	15	20	25	30	40	50	60
I, Integration Improvement in db =	6	8.4	9.6	10.5	11.2	11.8	12.6	13.2	13.8

Integration Improvement, I = 12 db

c. Integrated $(S/N)_i$

$$(\frac{S}{N})_i = (\frac{S}{N})_1 \text{ (db)} + I\text{db} = 24.4 \text{ db}$$

3. Calculation of $\left(\frac{S}{C_\omega}\right)_i$

a. Single Pulse $(S/C_\omega)_1$

Parameter	Value	Units	db Representation	Multiply By	Add db Results
σ_T : Target RCS	1000	M^2	30 db	+1	+30 db
λ : Wavelength	3.22	cm	5.1 db	+4	+20.4 db
W : Rain Rate	1	mm/hr	0 db	-1.6	-0 db
AZ : AZ Beamwidth	2	deg.	3 db	-1	-3 db
EL : EL Beamwidth	2	deg.	3 db	-1	-3 db
τ : Pulse Length	1	μ sec	0 db	-1	-0 db
R : Range	40	NM	16 db	-2	-32 db
Factor					+ 4.87 db

$(S/C_\omega)_1 =$ 12.3 db

b. Integration Factor

Integration Improvement, I, from 2b. = 12 db

c. Pulse Compression Ratio

Pulse Compression Ratio = 1 unitless

The Pulse Compression Factor, CR, is the decibel representation of the unitless Pulse Compression Ratio.

Therefore, Pulse Compression Factor, CR = 0 db

d. Integrated $(S/C_\omega)_i$

$$\left(\frac{S}{C_\omega}\right)_i = \left(\frac{S}{C_\omega}\right)_{1db} + I_{db} + CR_{db} = 29.3 \text{ db}$$

4. Calculate $\left(\frac{S}{C_{S/L}}\right)_i$

a. Clutter Reflectivity

(1). Depression Angle, θ, from 1a. = 1.5 deg.

Radar Band = X

Clutter Type = S.S.3

Clutter Reflectivity, σ_o, from Clutter values Appendix A. = 39 db.

(2). Pulse Compression Effect:

Parameter	Value	Units	Multiply By	Add db Results
σ_o : Clutter Reflectivity	39	+db	-1	-39
CR : From Sec. 3c.	0	+db	-1	-0

σ_o(EFF), Effective Clutter Reflectivity = -39 db.

b. Single Pulse $\left(\frac{S}{C_{S/L}}\right)_1$

Parameter	Value	Units	db Representation	Multiply by	Add db Results
σ_T : Target RCS	1000	M^2	30 db	+1	+30 db
τ : Pulse Length	1	μsec	0 db	-1	-0 db
R : Range	40	NM	16 db	-1	-16 db
AZ : AZ Beamwidth	2	deg.	3 db	-1	-3 db
σ_o(EFF): From Sec. 4a.	-39	db	→	-1	+39 db
Factor					→ -35.35 db

Single Pulse $\left(\frac{S}{C_{S/L}}\right)_1$ = 14.6 db

c. Integrated $\left(\frac{S}{C_{S/L}}\right)_i$

$\left(\frac{S}{C_{S/L}}\right)_1$ (from Sec. 4b.) = 14.6 db

I (From Sec. 2b.) = 12 db

$\left(\frac{S}{C_{S/L}}\right)_i = \left(\frac{S}{C_{S/L}}\right)_1 + I$ = 26.6 db

5. Calculate $\left(\frac{S}{N + C_\omega + C_{S/L}}\right)_i$

a. Calculate "Energy" Ratio

Parameter	Value	Units	Multiply By	Add Ratio Representation
$(S/N)_i$: Section 2c.	24.4	db	-1	.0035
$(S/C_\omega)_i$: Section 3d.	29.3	db	-1	.0015
$(S/C_{S/L})_i$: Section 4c.	26.6	db	-1	.0025

E, Inverse "Energy" Ratio = .0075 unitless

b. Integrated $\left(\frac{S}{N + C_\omega + C_{S/L}}\right)_i$

Parameter	Value	Units	db Representation	Multiply By	$\left(\frac{S}{N+C_\omega+C_{S/L}}\right)_i$ db
E, Sec. 5a.	.0075	unitless	-21.3 db	-1	+21.3 db

$\left(\frac{S}{N + C_\omega + C_{S/L}}\right)_i$ = +21.3 db

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13. ABSTRACT

This report provides a work form and rationale to perform hand calculations of the radar range equation. The techniques described cover the conventional geometric aspects of the radar equations as well as the effects of rain clutter, rain attenuation, atmospheric attenuation, sea and land clutter, and pulse integration for both conventional pulse and chirp clutter. It is complete, requiring no further texts, tables, references or slide rules.

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