[redacted]

UNCLASSIFIED

Technical Memorandum

SC-TM-71 0685
OCTOBER 1971

RECORD COPY
DO NOT TAKE FROM THIS ROOM

A REPORT ON CERTAIN EARLY COMPUTATIONS CONCERNING THE MURINE RADAR (U)

CHARLES S. WILLIAMS
SIGNAL ANALYSIS DIVISION 1424

SANDIA SYSTEMATIC DECLASSIFICATION REVIEW
1st Review Date: 1-10-96
Authority: ☐ ADC ☒ ADD
Name: W. C. Layne
2nd Review Date: 1-23-96
Authority: ADD
Name: R.K. Petersen
Determination (Circle Numbers):
1. Classification Retained
2. Classification Changed to: U
3. Contains No DOE Classified Information
4. Coordinate With:
5. Contains UCAI?
6. Comments:

~~This is a SANDIA CORPORATION working paper and is intended primarily for internal distribution; the ideas expressed herein do not necessarily reflect the opinion of the Corporation.~~

~~This memorandum is not to be reproduced without the express written permission of SANDIA CORPORATION.~~

~~DEFENSE INFORMATION~~

~~THIS MATERIAL CONTAINS INFORMATION AFFECTING THE NATIONAL DEFENSE OF THE UNITED STATES WITHIN THE MEANING OF THE ESPIONAGE LAWS, TITLE 18, U. S. C. SECS. 793 AND 794. THE TRANSMISSION OR REVELATION OF WHICH IN ANY MANNER TO AN UNAUTHORIZED PERSON IS PROHIBITED BY LAW.~~

~~GROUP 1 — EXCLUDED FROM AUTOMATIC DOWNGRADING AND DECLASSIFICATION.~~

SANDIA SYSTEMATIC DECLASSIFICATION REVIEW
DOWNGRADING OR DECLASSIFICATION STAMP
CLASSIFICATION CHANGED TO: U
AUTHORITY: R. K. Petersen
Emelda Selph 05/23/96
PERSON CHANGING MARKING & DATE
RECORD ID: 96SN010
R.K. Peterson 6/19/96
PERSON VERIFYING MARKING & DATE
DATED: 01-23-96

UNCLASSIFIED

SANDIA LABORATORIES
OPERATED FOR THE UNITED STATES ATOMIC ENERGY COMMISSION BY SANDIA CORPORATION | ALBUQUERQUE, NEW MEXICO, LIVERMORE, CALIFORNIA

[redacted]

[redacted]

UNCLASSIFIED

Issued by Sandia Corporation,
a prime contractor to the United States Atomic Energy Commission

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

UNCLASSIFIED

[redacted]

[redacted]

UNCLASSIFIED

SC-TM-71 0685

A REPORT ON CERTAIN EARLY COMPUTATIONS CONCERNING THE MURINE RADAR (U)

C. S. Williams
Signal Analysis Division 1424
Sandia Laboratories, Albuquerque

Date Completed: September 1971

Abstract (U)

This report shows that an average power of about 4 watts and a decision time of about 0.6 s are required by a helicopter-borne radar to detect a missile of 10^{-2} m^2 radar cross section closing at 500 m/s at a range of 425 m. For a helicopter height of 50 m, the ground-echo power is some 7 orders of magnitude above the signal; this ground clutter can be separated from the signal by coherent detection followed by Doppler filtering since the helicopter velocity is 50 m/s.

UNCLASSIFIED

[redacted]

[redacted]

UNCLASSIFIED

A REPORT ON CERTAIN EARLY COMPUTATIONS
CONCERNING THE MURINE RADAR (U)

In September 1970, Department 1420 (then 2620) made a presentation at the Sandia Laboratories to Don Cotter of ARPA concerning a proposed radar to be used aboard a helicopter to detect an approaching missile such as the Redeye. The radar is intended to give a warning about one second before the missile intercepts the helicopter. The attached handwritten notes were prepared by C. S. Williams, 1424 (then 2625), either shortly before or shortly after his presentation to Cotter. In either case, the conclusions concerning the feasibility of the radar (now informally designated Murine or Murene--since it is anti-Redeye) were based partly on these notes. The conclusions of Reference 1 are based on the formulas given in the notes; Reference 2 explicitly refers to them. The purpose of the present memorandum is to document the work represented by the notes.

The principal purpose of the notes was to make a quick determination of the feasibility of the Murine radar. The problems examined were the strength and spectrum of the ground clutter compared to the signal and the amplifier-noise power compared to signal power. Most of the assumptions appear in the notes but are repeated here:

Missile closing velocity, $-\dot{R}$:	$200 \text{ m/s} < -\dot{R} < 500 \text{ m/s}$
Range to missile at appearance:	Between 150 m and 500 m (Low closing velocity at short range, high at long)
Missile radar cross section:	$\sigma_{targ} = 10^{-2} \text{ m}^2$
Terrain radar cross section per unit area:	$\sigma_o = 1 \text{ m}^2/\text{m}^2$ (This value assumed but not given in the notes)

UNCLASSIFIED

[redacted]

UNCLASSIFIED

Helicopter ground speed:	50 m/s
Helicopter height:	50 m
Detection time:	About 1 s before intercept

Figure 1 presents the block diagram assumed for the calculations given in the notes. There are several channels in the receiver, each corresponding to a different range setting R_o. The signal output of the Doppler filter in each channel has the appearance of $v_3(t)$ shown at the bottom of page 3 of the notes with the peak occurring when $R = R_o$ and a duration in range from $R_o + \Delta R$ to $R_o - \Delta R$; thus, its time duration is $2\Delta R/|\dot{R}|$ seconds. (The signal waveform shown holds for $R_o \gg \Delta R$. Such is not the case in this application. As a result, the triangular envelope is distorted by the dependence on the signal component of $v_3(t)$ on R, the range to the target. However, in the calculations, we chose to neglect this effect.)

The transmitter is assumed to have random $0,\pi$ phase modulation with dwell time T on each value, and power P_o. This corresponds to amplitude modulation m(t)--see notes--where m(t) is +1 or -1 randomly. (The results here apply also for transmission with a duty ratio less than unity provided P_o is taken to represent average power.) This leads to the autocorrelation function $R_m(t)$ of m(t) shown on page 2 of the notes. The relationship between T and ΔR is given there as $T = 2\Delta R/c$ s where $c = 3 \times 10^8$ m/s is the propagation velocity of electromagnetic waves in vacuo.

On page 5 of the notes, the clutter (ground-echo) power is shown to be some 7 orders of magnitude greater than the peak signal power. It is also shown that the two are separated spectrally so that very little clutter power will appear at the output of the Doppler filter of transfer function H(f) if it has a sharp edge between the signal frequency and the maximum clutter frequency. These notes do not consider the effect of nonlinearity in the RF amplifier (not shown in Figure 1) on the clutter spectrum (however, see References 2 and 3); nor is the customary model of Reference 4 that was used to

UNCLASSIFIED

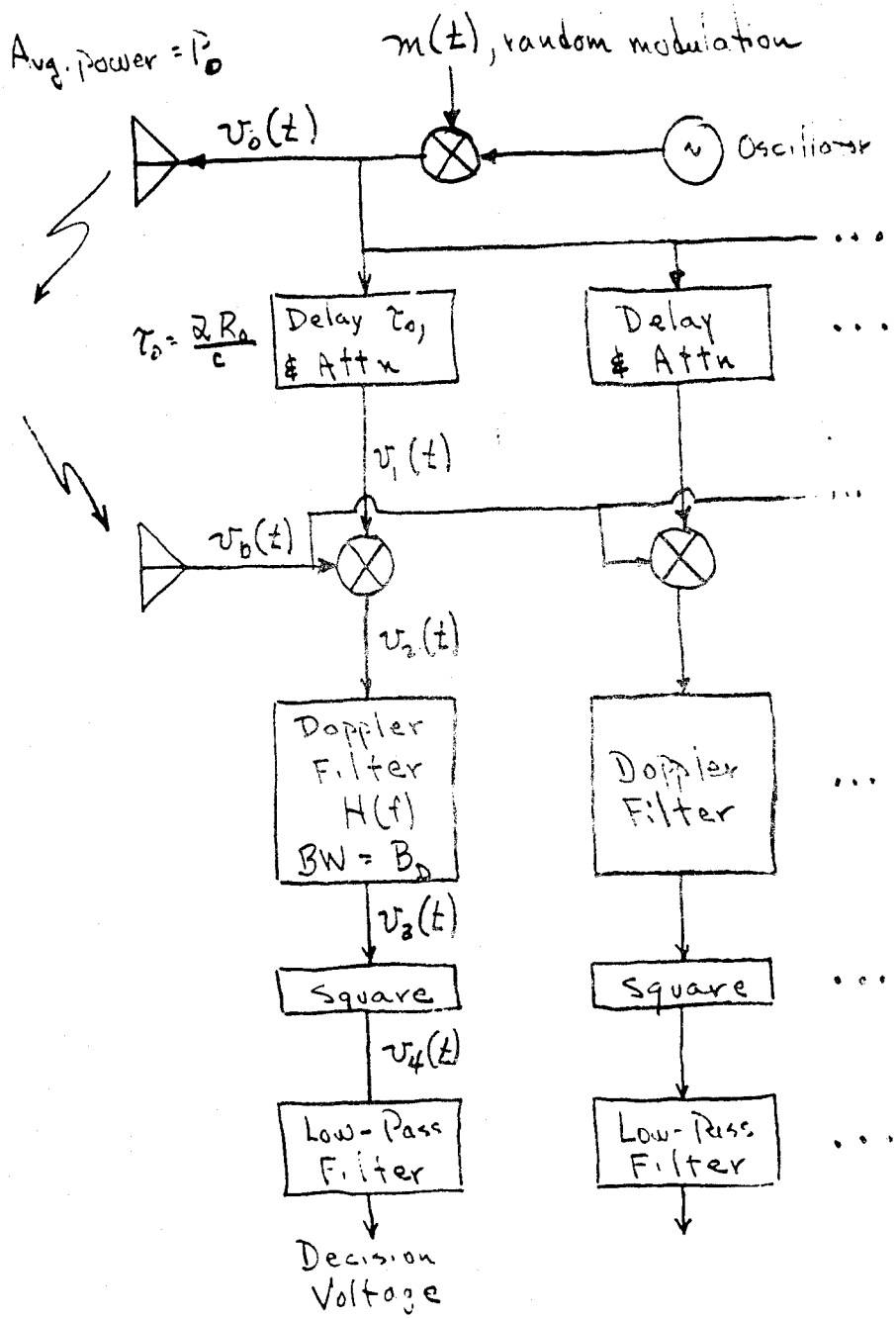


Figure 1. A block diagram for a Murine radar.

calculate the clutter spectrum reexamined to determine how sharply the clutter spectrum actually cuts off at its upper edge. (E. A. Aronson, Division 1424, has made calculations with a different and somewhat more accurate model which indicate that the cut-off is quite sharp. This work has not yet been documented.)

Under the assumption that the clutter power can be eliminated by a good Doppler filter, the formula at the bottom of page 6 of the notes gives the average transmitter power $P_{o(req)}$ required to provide successful operation. In that formula, we must take

$$\eta = (kK/2)F_N \quad W/Hz$$

where $k = 1.38 \times 10^{-23}$ W/Hz-deg is Boltzmann's constant, $K = 300^{o}$ Kelvin is the absolute temperature, and F_N is the RF-amplifier noise figure. Also we take $B_D = 3.0$ kHz; this is the bandwidth of the Doppler filter and is based on the maximum and minimum closing velocities 500 and 200 m/s and the RF wavelength $\lambda = 0.2$ m.

The average transmitter-power requirement $P_{o(req)}$ is based on a desired value of 7 for the ratio of the increase of the mean of the decision voltage due to a signal appearance to its standard deviation. If the low-pass filter is matched to the signal, this squared ratio (about 50) is equal to the ratio of signal energy at filter input to noise-power density there. This principle is used in the last section of page 6 of the notes. The principle, while optimistic, gives a reasonably good result since the filter can be fairly well matched for worst conditions.

Since $P_{o(req)}$ is proportional to R_o^4, the worst case will occur at the largest value of R_o. Let us assume a ranging scheme where $R_o = 425$ m and $\Delta R = 150$ m. (Then, in the first range channel of Figure 1, $\tau_o = 2R_o/c = 3.17$ μs. The range setting R_o will be different for the other channels to take care

of those cases where the target first appears at shorter ranges. However, ΔR will be the same for all since $\Delta R = cT/2$, where T, the modulation-function dwell time, is a parameter of the transmitter.) Thus, the signal at the Doppler-filter output will begin to rise as the target comes into a range of 575 m, will peak at a range of 425 m (if we calculate the signal strength as though the range were fixed at $R_o = 425$ m), and will drop out at R = 275 m. The total duration at the maximum closing velocity of 500 m/s is (300 m)/(500 m/s) = 0.6 s. (The low-pass filter in this channel should be matched to a signal of this duration.)

For the criterion that has been used on the decision voltage (viz., $\Delta\mu_d/\sigma_d > 7$ where the change $\Delta\mu_d$ in the decision-voltage mean μ_d is due to signal appearance and σ_d is its standard deviation) we have learned in previous similar analyses that it will cross the decision threshold on the average at about the middle of the signal interval, i.e., when $R \doteq R_o = 425$ m. This crossing will provide a warning about (425 m)/(500 m/s) = 0.85 seconds prior to interception. The average transmitter power needed for this case may be calculated from the last formula in the notes and is

$$P_{o(req)} = 3.9 \text{ W} .$$

We have used a noise figure of 5 dB for this result, i.e., $F_N = 10^{0.5} = \sqrt{10}$. (In the calculation at the bottom of page 6 of the notes, F_N was taken to be 1--a very optimistic estimate--and both R_o and ΔR have values different from those used just above.)

Conclusions

These computations were made for an early estimate of the problem caused by ground clutter and of the required transmitter power in the Murine radar. The conclusion was that filters could be obtained that would separate the clutter from the signal and that the transmitter could be a solid-state device.

Since these computations were made, the Murine radar has evolved somewhat and, in fact, continues to evolve. The same principles are used, but the block diagram is no longer the same. Clearly, other ranging schemes may be preferable to meet the requirements for providing an adequately early warning. Also, the difficulties that arise as a result of nonlinearities in the RF amplifier have been examined and surmounted. See References 2 and 3. Preliminary testing has indicated that the upper edge of the clutter spectrum cuts off fairly sharply as the Reference-4 theory predicts, and that the shifted clutter spectra caused by the rotating helicopter blades are of so little power that they do not interfere with the signal.

[redacted]

UNCLASSIFIED

NOTES ON THE MURINE RADAR

Prepared in September 1970, by
Charles S. Williams, (now) 1424.

These handwritten notes, when separated from this document, are unclassified.

UNCLASSIFIED

[redacted]

Target Return Average Power P_b

Average transmitter power: P_o
Antenna -- isotropic: $G^2 = 1$
Wavelength: $\lambda = 0.2$ m (1.5 GHz)
Target cross section: $\sigma_{targ} = 10^{-2}$ m^2
Target distance -- R: $R_{max} = 500$ m, $R_{min} = 150$ m

$$P_b = \frac{G^2 \lambda^2 \sigma_{targ} P_o}{64 \pi^3 R^4}$$

$$= 3.23 P_o \times 10^{-18} \text{ at } 500 \text{ m} = R_{max}$$

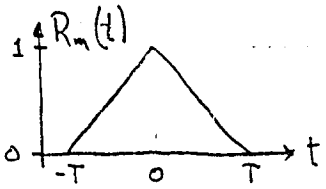
$$= 3.99 P_o \times 10^{-16} \text{ at } 150 \text{ m} = R_{min}$$

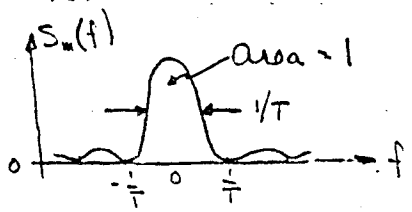
Page 2

Radar Processing Scheme

Transmission

$$v_0(t) = \sqrt{2P_0}\, m(t) \cos(2\pi f_0 t + \phi_0) \quad \text{V}$$





$T = 2\Delta R/c$, ΔR = range accuracy

Receiver input

Signal: $v_b(t) = \sqrt{2P_b}\, m(t-\tau) \cos[2\pi f_0 (t-\tau) + \phi_0]$ V

$$\tau = 2R/c = 2(R_0 + \dot{R}t)/c$$

$\tau - \tau_0 = 2\dot{R}t/c$, $\tau_0 = 2R_0/c$, R_0 = range setting

$-\dot{R}$ = closing velocity

Thermal noise: $S_{v_b}(t) = \eta$ W/Hz

Ground: $v_g(t) = \sum_i \sqrt{2P_i}\, m(t-\tau_i) \cos[2\pi(f_0+f_i)t - 2\pi f_0 \tau_0 + \phi_i]$ V

$f_i = (2V_i/c) f_0$, V_i = helicopter velocity toward i^{th} element

ϕ_i = random phase angles, mutually independent

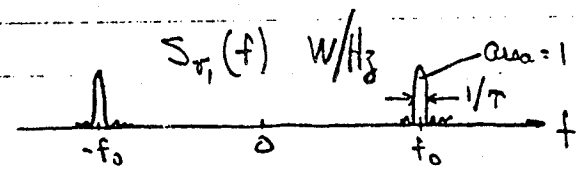
$\tau_i = 2r_i/c$, r_i = distance to i^{th} element on ground

$$P_i = \frac{G^2 \lambda^2 P_0 \sigma_0 \Delta A_i}{(4\pi)^3 r_i^4}$$

Page 3

Local input to mixer (delayed transmission)

$$v_1(t) = 2m(t-\tau_0)\cos[2\pi f_0(t-\tau_0)+\phi_0] = \sqrt{2P_0}\, v_0(t-\tau_0) \quad \checkmark$$



Mixer output

Signal: $v_2(t) = v_1(t)\, v_b(t)$

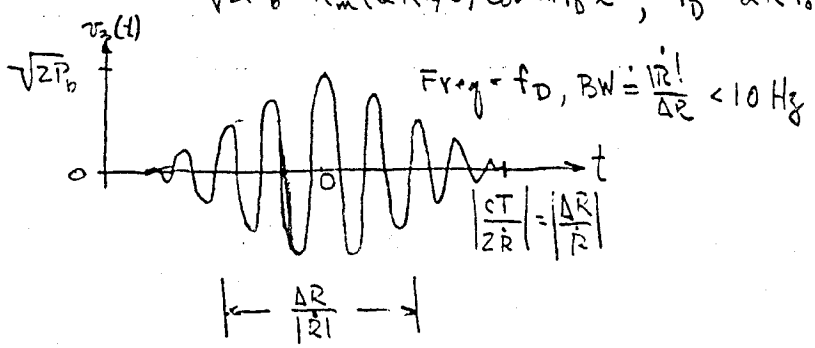
Thermal noise: $S_{v_2}(f) = 2\eta$

Ground: $v_2(t) = v_1(t)\, v_g(t)$

Doppler-filter output

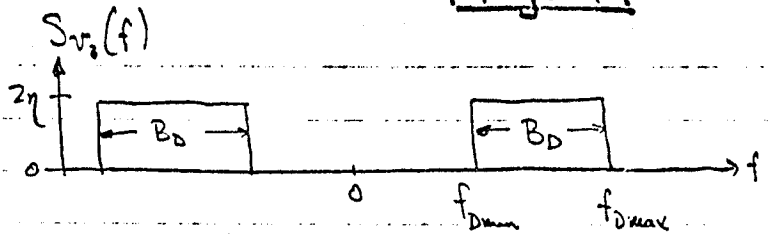
Signal: $v_3(t) = v_2(t) * h(t)$

$$= \sqrt{2P_b}\; R_m(2\dot{R}t/c)\cos 2\pi f_D t \;, \quad f_D = -2\dot{R}f_0/c$$



Page 4

Thermal noise:



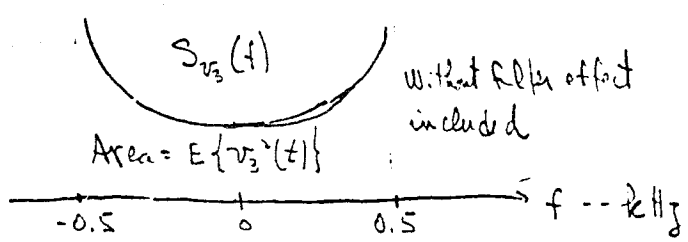
Ground: $v_3(t) = \sum_i \sqrt{2P_i}\, R_m(\tau_i - \tau_0) \cos[2\pi f_i t + \hat{\phi}_i]$

i such that $f_{Dmin} < |f_i| < f_{Dmax}$

$$E\{v_3^2(t)\} = \sum_i P_i R_m^2(\tau_i - \tau_0) \cdot |H(f_i)|^2$$

$$= \frac{\lambda^2 P_0 \sigma_0}{(4\pi)^3} \int \frac{R_m^2(2r/c - \tau_0)}{r^4}\, dA \otimes |H_g(f_i)|^2$$

$$\doteq \frac{\lambda^2 P_0 \sigma_0}{64\pi^2} \left[\frac{1}{(R_0 - \frac{\Delta R}{2})^2} - \frac{1}{(R_0 + \frac{\Delta R}{2})^2} \right] \otimes |H_g(f_i)|^2$$



without filter effect included

Helicopter velocity = 50 m/s

Max doppler = $2(50)/0.2$ = 500 Hz

Helicopter height = 20 m or so

[redacted]

$$\frac{\text{Ground power (before filter)}}{\text{Peak signal power}} = \frac{\lambda^2 P_0 \sigma_0}{64\pi^2} \cdot \frac{64\pi^3 R_0^4}{\lambda^2 P_0 \sigma_{targ}} \left[\frac{1}{\left(R_0 - \frac{\Delta R}{2}\right)^2} - \frac{1}{\left(R_0 + \frac{\Delta R}{2}\right)^2} \right]$$

$$= \frac{\pi \sigma_0 R_0^2}{\sigma_{targ}} \left[\frac{1}{\left(1 - \frac{\Delta R}{2R_0}\right)^2} - \frac{1}{\left(1 + \frac{\Delta R}{2R_0}\right)^2} \right]$$

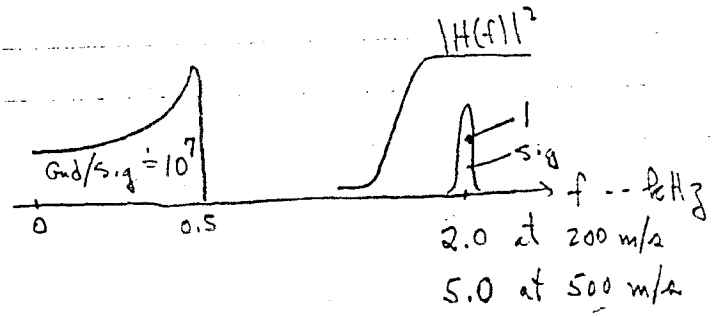
$\sigma_0 = 1$ used here. cw 9/30/71

$= 5.73 \times 10^6$ $\quad R_0 = 175\,m,\ \Delta R = 50\,m$

$= 1.669 \times 10^7$ $\quad R_0 = 525\,m,\ \Delta R = 50$

$= 3.02 \times 10^7$ $\quad R_0 = 275\,m,\ \Delta R = 150\,m$

$= 4.25 \times 10^7$ $\quad R_0 = 425\,m,\ \Delta R = 150\,m$



$|H(f)|^2$ must drop about 80 dB in 2 octaves

Page 6

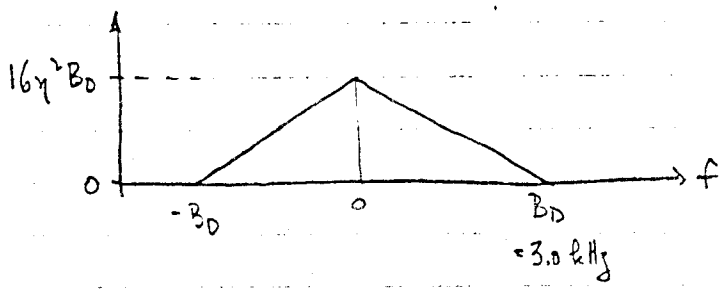
Square-law-detector output

Signal: $v_4(t) = P_b R_m^2 (2\dot{R}t/c)\left[1+\cos 4\pi f_D t\right]$

$$W_{sig} = \int_{-\infty}^{\infty} v_4^2(t)\,dt$$

$$\doteq \overset{3}{\cancel{2}} P_b^2 \Delta R / 5|\dot{R}|$$ corrected 9/30/71 cow

Thermal noise: $S_{v_4}(f) = \left[E\{v_3^2(t)\}\right]^2 \delta(f) + 2 S_{v_3}(f) * S_{v_3}(f)$



Power requirement

$$\frac{W_{sig(req)}}{S_{v_4}(0)} = \frac{\overset{3}{\cancel{2}} P_b^2 \Delta R}{5|\dot{R}|\ 16\eta^2 B_D} \overset{req}{=} 50$$ corrected 9/30/71 cow

$$\therefore\ P_{b(req)}^2 = (250)\overset{(16/3)}{\cancel{(8)}}\eta^2 B_D \dot{R}/\Delta R = \left(\lambda^2 P_{o(req)} \sigma_{targ} / 64\pi^3 R_o^4\right)^2$$

$$P_{o(req)} = \frac{64\pi^3 R_o^4}{\lambda^2 \sigma_{targ}} \sqrt{\frac{2\times10^3\ \eta^2 B_D |\dot{R}|}{\Delta R} \times \frac{2}{3}}$$

Correction factor added 9/30/71 cow

$$= 9.93\ W \times \sqrt{2/3}$$

for $R_o = 500$ m, $\Delta R = 50$ m, $\sigma_{targ} = 10^{-2}$ m^2, $G^2 = 1$, $\eta = kT_R = 2(300°K)$, $\lambda = 0.2$ m, $|\dot{R}| = 500$ m/s, $B_D = 3.0$ kHz

References

1. "The Murine Radar (U)," RS 2625/085, dated 8 October 1970, by C. S. Williams.

2. Confidential memorandum, R. L. O'Nan, 2623, to J. R. Ames, 2623, re "A Proposal for the Toonerville Trolley Experiment," dated 4 December 1970.

3. "Analysis of a Murine Test Radar, Including Nonlinear-Amplifier Effects--A Preliminary Report," SC-TM-71 0752, by C. S. Williams, 1424 and E. A. Aronson, 1424, to be published.

4. "Interpretation and Prediction of Radar Terrain Return Fading Spectra--Progress Reports I, II, and III," SCR-212, SCR-214, and SCR-215, dated July 1960 by Peter D. Welch. (Originally issued as reports of the Physical Science Laboratory of New Mexico State University: AER-14W dated 25 May 1955; AER-18B dated 15 February 1956; and AER 18C dated 30 May 1956.)

Distribution:
W. C. Myre, 1210
R. L. Peurifoy, 1220
C. R. Blaine, 1221
R. S. Claassen, 1400
G. W. Rodgers, 1420
C. R. Alls, 1421
J. R. Ames, 1422 (2)
  Attn: R. L. O'Nan
E. A. Aronson, 1424
C. S. Williams, 1424 (10)
J. A. Cooper, 1426
T. M. Burford, 1700
R. J. Thompson, 1722
R. S. Gillespie, 3151
W. K. Cox, 3142-1 (15)
L. S. Ostrander, 8232