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CLASSIFICATION UNCLASSIFIED	**SYSTEM NUMBER** 517745

TITLE

A Real Aperture, Sidelooking, Ocean Surveillance, Space-based Radar

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A Real Aperture, Sidelooking, Ocean Surveillance, Space-based Radar

Ron Martin

Defence R&D Canada
TECHNICAL MEMORANDUM
DREO TM 2001-064
August 2001

National Defence Défense nationale
Defence nationale

Canada

A Real Aperture, Sidelooking, Ocean Surveillance, Space-based Radar

Ron Martin
Defence Research Establishment Ottawa

DEFENCE RESEARCH ESTABLISHMENT OTTAWA
TECHNICAL MEMORANDUM
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Abstract

A result of global warming is the opening of passageways through previously ice-jammed arctic waterways Consequently, the ability to monitor sea traffic through these regions is gaining in importance Options for achieving this goal include reconnaissance with long range patrol aircraft, the use of surface wave radars strategically located in the north and surveillance from space platforms This report discusses the latter solution

A relatively inexpensive space-based radar has be proposed that can provide detection, finger-printing and tracking of ships as small as corvette-sized naval craft The RF power requirements, based on a target of 1000 m^2 radar-cross-section, are quite modest, being 157 watts of average power A four-fold increase in RF power to 628 watts would allow detection, in thermal noise at least, of fast patrol boat-sized craft having cross sections down to 250 m^2 The problem is not, however, detection in thermal noise but against the sea clutter which may limit the detection of smaller craft to relatively low sea state conditions (sea state 3 or less)

Résumé

Le réchauffement de la planète a pour effet d'ouvrir des passages dans les eaux arctiques navigables, auparavant pleines d'embâcles Il est donc de plus en plus important de pouvoir surveiller la circulation maritime dans ces régions Cela peut se faire au moyen d'avions de patrouille à long rayon d'action, de radars à ondes de surface situés dans le Nord en des points stratégiques ainsi que de plates-formes spatiales Le rapport étudie cette dernière solution

Un radar spatial relativement peu coûteux a été proposé pour la détection, la détermination des empreintes spectrales et la poursuite de navires aussi petits que les corvettes La puissance RF nécessaire pour une cible d'une surface équivalente radar (SER) de 1000 m^2 est plutôt modeste, soit de 157 watts de puissance moyenne Une puissance quatre fois supérieure, soit de 628 watts, permettrait de détecter, du moins sur un fond de bruit thermique, des bâtiments de guerre rapides de la taille de patrouilleurs, ayant une SER de 250 m^2 et plus Toutefois, le problème n'est pas la détection sur fond de bruit thermique, mais la détection sur fond de clutter de mer, qui peut limiter la détection d'embarcations plus petites aux états de mer relativement bas (niveau 3 ou moins)

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Executive Summary

A result of global warming is the opening of passageways through previously ice-jammed arctic waterways Consequently, the ability to monitor sea traffic through these regions is gaining in importance Options for achieving this goal include reconnaissance with long range patrol aircraft, the use of surface wave radars strategically located in the north and surveillance from space platforms This report discusses the latter solution

A relatively inexpensive space-based radar has be proposed that can provide ocean surveillance of sea targets down to corvette-sized naval craft The RF power requirements, based on a 1000 m^2 target, are quite modest, being only 157 watts A four-fold increase in RF power to 628 watts would allow detection in thermal noise of fast patrol boat-sized naval craft with radar cross sections down to 250 m^2 The problem is not, however, detection in thermal noise but detection against the sea clutter With the simple processing used in this study being incoherent processing with frequency agility, only a small margin exists for target detection at the near grazing angle The standard approach of reducing the clutter power by reducing the clutter echoing area through high range resolution would appear to be ineffective as a further increase in resolution over that used here would start to over-resolve targets reducing their effective RCS

The use of incoherent rather than coherent processing by doppler filtering permits the use of PRF's below values required for Nyquist rate sampling of the sea clutter Had coherent processing been used, a PRF of about 1500 Hz would have been required, an increase in frequency by a factor of ten, with a consequent reduction in the unambiguous swath coverage to 100 kilometers Using incoherent detection, the signal processing chain is simplified, data rates are lower, and data storage requirements are diminished

A separate spacecraft, devoted to ocean surveillance, could be deployed with the above radar or an ocean surveillance mode using this system could be part of the "signal" repertoire of a future space-based radar such as the Radarsat 4 synthetic aperture radar It would be very interesting, for example, to compare the detection performance of a radar using incoherent integration with that of a radar using the coherent processing of synthetic aperture imaging and detection

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Sommaire

Un radar spatial relativement peu coûteux a été proposé pour la surveillance d'objectifs maritimes de la taille d'une corvette ou de taille supérieure La puissance RF nécessaire pour une cible de 1000 m^2 est plutôt modeste, soit de 157 watts Une puissance quatre fois supérieure, soit de 628 watts, permettrait de détecter, sur un fond de bruit thermique, des bâtiments de guerre rapides de la taille de patrouilleurs, ayant une section efficace radar (SER) de 250 m^2 et plus Toutefois, le problème n'est pas la détection sur fond de bruit thermique, mais la détection sur fond de clutter de mer Le traitement incohérent avec agilité en fréquence, méthode simple utilisée dans la présente étude, ne laisse qu'une faible marge pour la détection de cibles près de l'incidence rasante La méthode courante de réduction du clutter, consistant à réduire la zone d'écho de clutter à l'aide d'une haute résolution en distance, semblerait inefficace, car l'augmentation de résolution produirait une résolution excessive des cibles, ce qui diminuerait la SER de celles-ci

L'utilisation du traitement incohérent au lieu du traitement cohérent avec filtrage Doppler permet d'utiliser des PRF inférieures aux valeurs nécessaires à l'échantillonnage Nyquist du clutter de mer Le traitement cohérent aurait exigé une PRF d'environ 1500 Hz, soit une augmentation de la fréquence par un facteur de dix, ce qui aurait réduit à 100 kilomètres la largeur de la bande au sol non ambigue La détection incohérente permet de simplifier la chaîne de traitement des signaux, de réduire les débits de données et de diminuer les besoins de stockage de données

Il serait possible de déployer, avec le radar précité, un engin spatial distinct consacré à la surveillance océanique, ou d'incorporer un mode de surveillance océanique au répertoire « signal » d'un futur radar spatial tel que le radar à ouverture synthétique Radarsat 4 Il serait très intéressant, par exemple, de comparer la performance de détection d'un radar à intégration incohérente avec celle d'un radar utilisant le traitement cohérent de l'imagerie et de la détection à ouverture synthétique

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1. INTRODUCTION

A result of global warming is the opening of passageways through previously ice-jammed arctic waterways. Consequently, the ability to monitor sea traffic through these regions is gaining in importance. Options for achieving this goal include reconnaissance with long range patrol aircraft, the use of surface wave radars strategically located in the north and surveillance from space platforms. This report discusses the latter solution.

A relatively inexpensive space-based radar has be proposed that can provide detection, finger-printing and tracking of ships as small as corvette-sized naval craft. This space-based system could either be an autonomous spacecraft or simply a mode of a future space platform such as Radarsat 4. A summary of the requirements and the assumptions made for the ocean surveillance radar is given in the next section.

2. REQUIREMENTS/ASSUMPTIONS

For the purpose of this analysis a carrier frequency of 3 GHz (S-band) was chosen, however, similar results can be obtained at L, C or even X-band. While the use of lower frequencies, L or P-band, may ease the problem of target detection in sea clutter, it invites problems in securing world-wide licensing to operate a radar spacecraft in these relatively crowded bands. The choice of orbit is a trade-off between power-aperture product and atmospheric drag. An orbital height of 650 km is a good compromise between these two factors. To facilitate both target tracking and fingerprinting, a 1D electronically-scanned aperture is assumed. To ensure that the platform provides a cost-effective solution to ocean surveillance a swath width of at least 1000 km was deemed to be necessary.

1. S-Band, $\lambda = 0.1$ m
2. Aperture length, $L = 10$ m
3. S/C Altitude, $h_p = 650$ km
4. Surveillance geometry/mode: sidelooking/real aperture radar
5. Swath, $Sw \geq 1000$ km
5. Target RCS, $\sigma_t = 1000\ m^2$
6. Minimum grazing angle, $\gamma_f = 0°$
7. Polarization: horizontal
8. Processing strategy: incoherent integration with frequency agility
9. Sea state: 3
10. 1D, electronically-scanned aperture, covering ±45° in azimuth

3. RADAR CROSS SECTION OF SHIPS

In reference [1] Skolnik has restated a “folk theorem” for the determination of a ship’s RCS based on the displacement of the vessel This reasonably accurate empirical expression is useful only when a single number for the RCS is needed such as in the determination of the required power-aperture product for a space-based surveillance radar The theorem states that at low grazing angles, but not zero degrees, the median value of the RCS can be expressed by the empirical relation (in metric units) as

$$\sigma_t = 1903\ f^{1/2}\ D^{3/2}\quad m^2 \tag{1}$$

where f is the radar frequency GHz
and D is the full-load displacement kilotonnes

The measurements upon which the above expression was developed were RCS values taken at X, S and L bands, averaged over the port and starboard bow and quarter aspects, of a number of ships having displacements from 2000 to 17 000 tons For a corvette-sized craft, such as the Russian Nanuchka class corvette with a displacement of 660 tons / 600 tonnes, the predicted RCS at 3 GHz is 1530 m^2 A value of 1000 m^2 for the target RCS has been used in this study

4. ANTENNA DESIGN

4.1 Antenna Height Based on Required Swath

Let the far grazing angle (see Figure 1), γ_f, be

$$\gamma_f = 0^\circ$$

and let the swath, Sw, be

$$Sw = 1000\ km$$

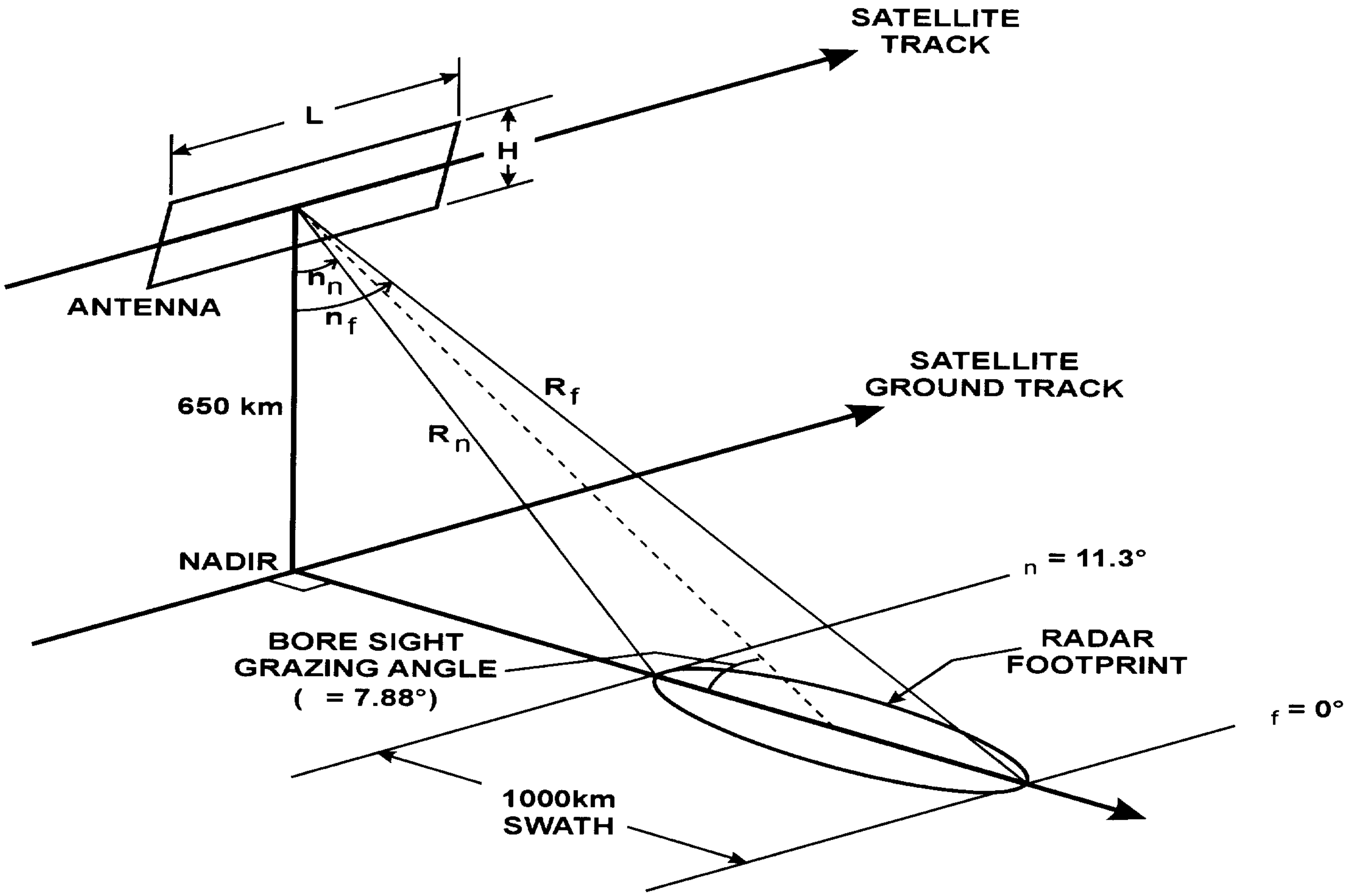
then the near grazing angle (see Figure 1), γ_n , is

$$\gamma_n = 11\ 3^\circ$$

For $\gamma_f = 0^\circ$
$n_f = 65\ 164^\circ$
where n_f is the far nadir angle (see Figure 1)

For $\gamma_n = 11\ 3^\circ$

Figure 1: Satellite Geometry



$n_n = 62\ 874$
where n_n is the near nadir angle (see Figure 1)

then $\gamma_{bs} = 7\ 88^{\circ}$
where γ_{bs} is the grazing angle at boresight (see Figure 1)

The vertical beamwidth is

$$\begin{aligned} BW_v &= n_f - n_n \\ &= 2\ 3^{\circ} \end{aligned} \qquad (2)$$

Now the vertical beamwidth is the two-way beamwidth, so

$$\begin{aligned} W &= k\lambda \,/\, (BW_v \times 2^{1/2}) \\ &= 2\ 11\ \text{m} \end{aligned} \qquad (3)$$

for $k = 1\ 2$
where k is the antenna weighting constant

A MATLAB program, used to obtain the above results, is given in Appendix 9 2

4.2 Aperture Details

The aperture is required to scan, electronically, in the azimuth (along-track) dimension so that both target tracking and target fingerprinting can be achieved The number of elements required to fill an aperture that is 10 meters by 2 11 meters is

$$\begin{aligned} N_e &= N_{el} \times N_{eh} \\ &= 10/\ 05 \times 2\ 11/0\ 05 \\ &= 200 \times 42 \end{aligned} \qquad (4)$$

where N_{el} is the number of elements in the length dimension
and N_{eh} is the number of elements in the height dimension

The aperture then is arranged as 200 vertical sticks each of 42 elements Each of the vertical sticks is center fed by a T/R module The required average power per T/R module is then the required P_{avg} / 200

5. TARGET DETECTION

5.1 Incoherent Integration

We first choose a PRF such that the corresponding unambiguous range is equal to the swath to be covered. Thus

$$\begin{aligned} LPRF &= c/(2\times Sw) \\ &= c/(2\times 1000e3) \\ &= 150 \text{ Hz} \end{aligned} \tag{5}$$

At γ_f the slant range from the spacecraft to the sea, R_f, is

$$R_f = 2952 \text{ km}$$

The instantaneous azimuthal coverage of the radar can be approximated by the"far"chord, Cd_f, so that

$$\begin{aligned} Cd_f &= k\lambda R_f/L \\ &= 35.42 \text{ km} \end{aligned} \tag{6}$$

Now the ground speed of the spacecraft, V_{gs}, is

$$V_{gs} = 6834.2 \text{ m/s}$$

and the time on target, T_{totf}, at the far range is

$$\begin{aligned} T_{totf} &= Cdf / V_{gs} \\ &= 5.2 \text{ s} \end{aligned} \tag{7}$$

The radar hits/beamwidth, N_{hf}, are then

$$\begin{aligned} N_{hf} &= PRF \times T_{totf} \\ &= 150 \times 5.2 \\ &= 777 \end{aligned} \tag{8}$$

Assuming that the processing gain against thermal noise is proportional to $N^{1/2}$ for uncorrelated returns, then the incoherent processing provides a gain of approximately

$$\begin{aligned} PG_f &= N_e \\ &= N_{hf}^{\ 1/2} \\ &= 28 \\ &= 14.5 \text{ dB} \end{aligned} \tag{9}$$

As the decorrelation time, T_{dec}, of the sea is about 30 ms at S-band [2] and the interpulse period, T_i, of the radar is 6 67 ms, then frequency agility will be required to ensure that the returns are uncorrelated For uniformly distributed, Rayleigh, clutter decorrelation occurs for frequency shifts greater that the bandwidth of the transmitted pulse [3] At the same time, target decorrelation will not occur if the frequency shift is less than c/2d, where d is the length of the ship For the baseline corvette , the length is 59 3 meters and consequently a shift of 2 5 MHz would be required to achieve target decorrelation whereas a shift of only 1 MHz is used here The number of unique frequencies required before returning to the original is

$$\begin{aligned} N_{agile} &= T_{dec} / T_i \\ &= 30 / 6\ 67 \\ &= 5 \end{aligned} \tag{10}$$

Without frequency agility, the minimum interpulse period is determined by the sea clutter decorrelation time of 30 ms, and consequently the PRF is 1/0 03 or 33 3 Hz With this value of PRF, the hits-on-target are reduced by a factor of 150/33 3 or 4 5 and the incoherent processing gain by a factor of $4\ 5^{1/2}$ or 3 3 dB

With pulse-to-pulse frequency agility, PRF's greater than 150 Hz could be used, however, local oscillator switching with memory would be required as with all HPRF radar systems For example, increasing the PRF by a factor of ten would increase the number of unique frequencies required by a factor of ten The hits-on-target would be increased by a factor of ten and the processing gain by $10^{1/2}$ or 5 dB For simplicity the radar is operated in a LPRF mode

5.2 Detection in Thermal Noise

Detection in thermal noise will be driven by detection requirements at the furthest range, R_{sf}, so that,

assuming $T_s = 500$ K
$L_s = 6$ dB $= 3\ 98$
$R_f = 2952$ km
$R_f^4 = 7\ 59e25$
$\lambda = 0\ 1$ m
$\lambda^2 = 0\ 01\ m^2$
$k = 1\ 38e\text{-}23$ Ws/K
$A = L \times H = 21\ 1\ m^2$
$A^2 = 445\ 21\ m^4$
$\sigma_t = 1000\ m^2$

and if $P_d = 0\ 9$, $P_{fa} = 10^{-6}$, the Swerling number is 1 (SW1) and N = 777 the required S/N per pulse is

$$S/N = 2\ 5\ \text{dB} = 1\ 78$$

and the average transmit power required is [4]

$$P_{avg} = 4\pi\, R^4\, k\, T_s\, L_s\, S/N\, \lambda^2 / (A^2\, \sigma_t\, T_i) \qquad (11)$$
$$= 157\ \text{W}$$

The average power that each T/R module must supply is 157/200 or about 1 Watt

5.3 Detection in Sea Clutter

The radar will be clutter-limited at the near grazing angle since clutter returns will be strongest there Thus, performance in clutter is determined at the near slant range, R_{sn}

When $\gamma = \gamma_n = 11\ 3^\circ$

$$R_n = 1957\ 7$$
$$Cd_n = k\lambda R_n / L \qquad (12)$$
$$= 23\ 49\ \text{km}$$

If $B = 1\ \text{MHz}$

then the range resolution, ρ_r, projected on the sea surface is

$$\rho_r = c/(2B\times\cos 11\ 3) \qquad (13)$$
$$= 150\ \text{m}$$

The clutter echoing area, A_c, is

$$A_c = \rho_r \times A_c \qquad (14)$$
$$= 150 \times 23\ 490$$
$$= 3\ 52e6\ \text{m}^2$$

Sea clutter models, developed by the Applied Physics Laboratory of JHU [4], were used to determine the value of σ_0 at 3 GHz with horizontal polarization, sea state 3 (SS 3) and a γ of 11 3° The value of σ_0 is determined in Appendix 9 1 as

$$\sigma_0 = -42\ \text{dBm}^2/\text{m}^2$$

The clutter cross section, σ_c, is now

$$\sigma_c = \sigma_0 \times A_c \qquad (15)$$
$$= 222\ 3\ \text{m}^2$$

and the signal / clutter ratio on a single pulse, $(S/C)_1$, is

$$\begin{aligned}(S/C)_1 &= \sigma_t / \sigma_c \\ &= 1000 / 222\ 3 \\ &= 4\ 49 \\ &= 6\ 52\ \mathrm{dB}\end{aligned} \tag{16}$$

At $\gamma_n = 11\ 3^\circ$, the time on target is

$$\begin{aligned}T_{totn} &= Cd_n / V_{gs} \\ &= 23\ 470 / 6834\ 2 \\ &= 3\ 43\ \mathrm{s}\end{aligned} \tag{17}$$

The hits/beamwidth are

$$\begin{aligned}N_{hn} &= 3\ 43 \times 150 \\ &= 515\end{aligned}$$

With this number of hits, the required S/C per pulse to obtain a $P_d = 0\ 9$ and a $P_{fa} = 10^{-6}$, assuming a Swerling 1 target, is 6 3 dB The actual S/C per pulse is 6 52 dB and the margin is only 0 22 dB

6. TARGET FINGERPRINTING

Electronic-scanning in azimuth allows the radar beam to scan-back both for target fingerprinting and to establish a target track The "fingerprinting" waveform uses a high range resolution signal to resolve the prominent scatters of the ship A step frequency waveform with a frequency sweep of 20 to 30 MHz is considered satisfactory for this purpose With this waveform, slant range resolutions of 7 5 to 5 meters are obtained True target classification would probably require an even larger bandwidth and, generally, a more complicated and expensive system

7. SPACECRAFT/RADAR PARAMETER SUMMARY

Orbital Height, $h_p = 650$ km

Orbital inclination near polar

Radar Frequency, $f_o = 3$ GHz

Average Transmitter Power, $P_{avg} = 157$ W

Length of Aperture, L = 10 m

Height of Aperture, H = 2.11 m

Swath, Sw = 1000 km

Target RCS, $\sigma_t = 1000$ m^2

Sea State, SS = 3

Polarization: horizontal

LPRF = 150 Hz

Uncompressed Pulse Length, $T_u = 33.35$ µs

Search waveform: agile, 5 step (1 MHz steps), LFM waveform

Fingerprinting waveform: multiple step, step frequency waveform,
overall bandwidth 20-30 MHz

Design probabilities: $P_d = 0.9$ and $P_{fa} = 10^{-6}$

Processing: incoherent with pulse-to-pulse frequency agility

Boresight grazing angle, $\gamma_{bs} = 7.88°$

Far grazing angle, $\gamma_f = 0°$

Near grazing angle, $\gamma_n = 11.3°$

8. CONCLUSIONS

A relatively inexpensive space-based radar has be proposed that can provide ocean surveillance of sea targets down to corvette-sized naval craft. The RF power requirements, based on a 1000 m^2 target, are quite modest, being 157 watts. A four-fold increase in RF power to 628 watts would allow detection, in thermal noise, of fast patrol boat-sized naval craft with radar cross sections down to 250 m^2. The problem is not, however, detection in thermal noise but detection against the sea clutter. With the simple processing used in this study (incoherent processing with frequency agility), only a small margin exists for target detection at the near grazing angle. The common approach of reducing the clutter power by reducing the clutter echoing area through high range resolution would appear to be ineffective as a further increase in resolution over the value used here would lead to target over-resolution and a consequent reduction in the effective target RCS.

The use of incoherent rather than coherent processing permits the use of pulse repetition frequencies below values that are required for Nyquist rate sampling of the sea clutter Had coherent processing been used, a PRF of about 1500 Hz would have been required, an increase in the repetition frequency by a factor of ten, with a consequent reduction in the unambiguous swath coverage to 100 kilometers Using incoherent detection, the signal processing chain is simplified, data rates are lowered, and data storage requirements are diminished

A separate spacecraft, devoted to ocean surveillance, could be deployed with the above radar as the payload or an ocean surveillance mode using this technique could be part of the "signal" repertoire of some future space-based radar such as one in the Radarsat series of synthetic aperture radars, possibly Radarsat 4 The forth version of Radarsat will provide, along with the routine Radarsat functions, a test bed for new techniques/concepts and may utilize a 2D electronically-scanned active aperture It would be interesting, for example, to compare the detection performance of a space-based radar using a real-aperture, incoherent integration mode with that of the normal, fully-coherent, synthetic aperture imaging mode To obtain good performance with incoherent integration, the radar must observe the ocean surface at low grazing angles in order to keep clutter levels low The current series of Radarsats, that is, 1, 2 and 3, are not able to scan out to the grazing angles required for best performance This shortcoming may be remedied with the forth spacecraft in this series

The number of surveillance spacecraft required to fulfil a given ocean surveillance mission depends, in part, on the latitude of the area under surveillance A single spacecraft in a 650 kilometer polar orbit revisits the arctic region every 97 7 minutes and, with fingerprinting, should be, in itself, quite adequate for northern ocean surveillance. If surveillance along the coasts of North America is required then more spacecraft, probably only a few though, will be required During the twenty years that the Russian wide-area Radar Ocean Reconnaissance Satellite, RORSAT was employed only one or at most two spacecraft were operational at the same time. The choice of S-band for the radar satellite would also allow the aperture to be shared with an S-band ESM system that could be used to detect emissions from ship navigation radars

For comparison purposes, parameter sets for both RORSAT and an Ocean Surveillance Spacecraft proposed by Skolnik are given in Appendices 9 3 and 9 4, respectively

9. Appendices

9.1 Clutter Calculations

In [5] the mean clutter reflection coefficient, σ_0, is given as

$$\sigma_0\ (\mathrm{dBm^2/m^2}) = \sigma_r + K_g + K_s + K_p + K_d$$

where σ_r is the reflectivity at the reference grazing angle, γ_r, of 0.1°
K_g is the grazing angle correction
K_s is the sea state correction (0 for SS 5)
K_p is the polarization correction (0 for vertical polarization)
K_d is the correction for wind direction (0 for the upwind condition)

For the space-based radar case, values of σ_0 are determined for SS3, horizontal polarization and for $\gamma = \gamma_n = 11.3°$. Thus, corrections for grazing angle, sea state and polarization are required. These are given below.

To determine the grazing angle correction, it is first necessary to calculate a transition angle, γ_t, which is

$$\begin{aligned}\gamma_t &= \mathrm{asn}(0.08516\lambda)\\ &= \mathrm{asn}(0.08516 \times 0.1)\\ &= 0.488°\end{aligned}$$

If $\gamma_t < \gamma_{near} < 30°$, then

$$\begin{aligned}K_g &= 20 \log (\gamma_t / \gamma_r) + 10 \log (\gamma_{near} / \gamma_t) \quad \mathrm{dB}\\ &= 13.77 + 13.65 \quad \mathrm{dB}\end{aligned}$$

Now, for SS 3, the correction is

$$\begin{aligned}K_s &= 5(SS\text{-}5)\ \mathrm{dB}\\ &= -10\ \mathrm{dB}\end{aligned}$$

If $3 \le f \le 10$ GHz, then

$$\begin{aligned}K_p &= -9.7 + 1.1\times\ln (0.08SS^2 + 0.015) - 1.1\times\ln \lambda - 1.3\times\ln(\gamma/57.3+0.0001)\\ &= -9.7 - 0.03386 + 2.533 + 2.11\\ &= -5.4\end{aligned}$$

The value of σ_0 at $\lambda = 0.1$ m, $\gamma = 11.3°$, SS3, and horizontal polarization, is then

$$\sigma_0 = \sigma_r + K_g + K_s + K_p \ \mathrm{dBm^2/m^2}$$

$$= -54 + 27\ 42 - 10 - 5\ 4\ \text{dBm}^2/\text{m}^2$$
$$= -42\ \text{dBm}^2/\text{m}^2$$

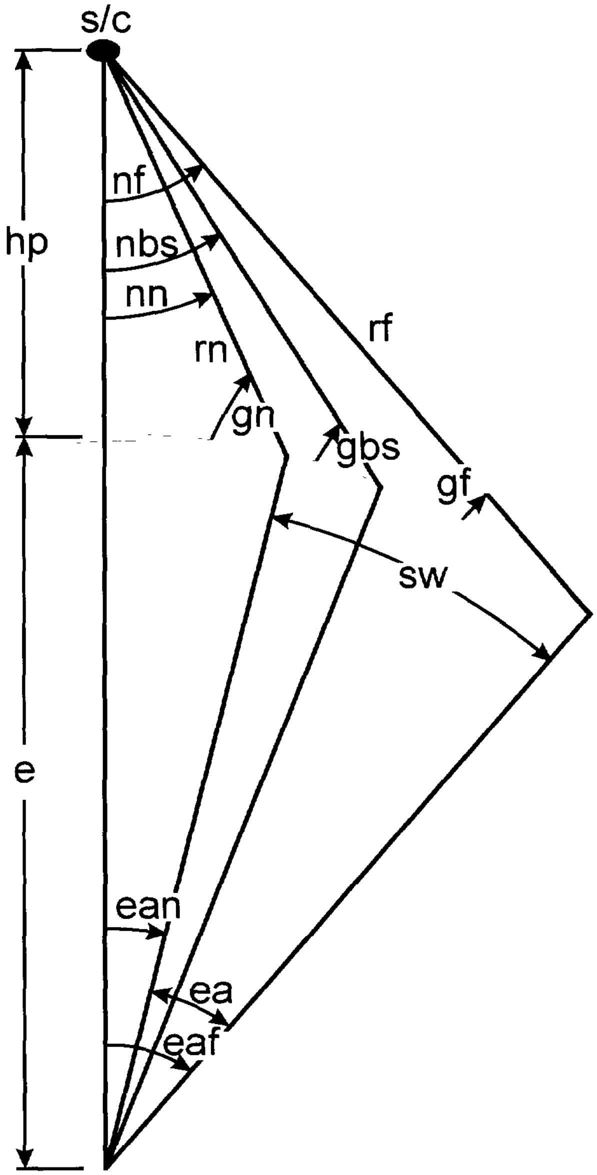
where σ_r is the value of σ at the reference angle of 0 1° is obtained from [4]

9.2 MATLAB Program Listing

```
%geom2 m
hp=650                          %s/c altitude km
sw=1000                         %swath km
wl= 1                           %wavelength m
k=1 2                           %antenna weighting factor
l=10                            %aperture length m
prf=150                         %PRF Hz
gfd=0                           % far grazing angle deg
e=6378 6                        %earth radius km
cir=2*pi*e                      %earth circumference km
a=hp+e                          %semi-major axis
vp=(3 986e11/a)^ 5              %platform velocity m/s
vg=vp*e/a                       %ground velocity m/s
vg=vg/1000                      %ground velocity km/s
gf=gfd/57.295                   %far grazing angle
nf=asin(e*sin(pi/2+gf)/a)       %nadir angle of gf
nfd=nf*57 295                   %nadir angle deg
eaf=pi/2-gf-nf                  %earth angle of gn
rf=a*sin(eaf)/cos(gf)           %slant range of gf km
ea=sw*2*pi/cir                  %earth angle subtended by swath
ean=eaf-ea                      %earth angle of gn
rn=(a^2+e^2-2*a*e*cos(ean))^ 5 %slant range of gn km
nn=asin(e*sin(ean)/rn)          %nadir angle of gn
nnd=nn*57 295                   %nadir angle deg
bw=nf-nn                        %beamwidth
bwd=bw*57 295                   %beamwidth deg
nbs=bw/2+nn                     %nadir angle of gbs (boresite)
gbs=pi/2-asin(a*sin(nbs)/e)     %grazing angle of gbs
gbsd=gbs*57 295                 %grazing angle at boresight deg
gn= pi/2-asin(a*sin(nn)/e)      %near grazing angle
gnd=gn*57 295                   %grazing angle deg
%antenna height calculation
h=k*wl/(1 414*bw)               %antenna height m
%near chord calculation
cdn=k*wl*rn/l                   %length of near chord km
%far chord calculation
cdf=k*wl*rf/l                   %length of far chord
%near hits/beamwidth
hn=prf*cdn/vg                   %near hits/beamwidth
hf=prf*cdf/vg                   %far hits/beamwidth
pgn=hn^ 5                       %near processing gain
pgf=hf^ 5                       %far processing gain
```

Geometrical details of the above program are given in Figure 2

Figure 2: MATLAB Program Geometrical Relationships



9.3 RORSAT Specifications

Information source In References [6, 7]

Name Radar Ocean Reconnaissance Satellite (RORSAT)

Country: USSR

Function Detect, localize and track ocean targets

Frequency X-band

Orbital height 265 km (near circular)

Orbital inclination 65°

Surveillance geometry/mode Sidelooking / real aperture radar

Antenna Slotted waveguide

RF Power source most probably, a magnetron

Power source Fast neutron reactor, the core contained 30 kg of 90% enriched uranium-235

Prime power 2-5 kW (estimated)

Body size 10 m × 1.3 m

First launch Kosmos 198, 27 December 1967

Last launch Kosmos 1988, 14 March 1988

Total spacecraft launched 31

Design lifetime 2-3 months

Picture of RORSAT In reference [7]

9.4 Ocean Surveillance Spacecraft/Radar Parameters

Source Skolnik MI in [8]

Orbital height = 278 km

Radar frequency 1 3 GHz

Average transmitter power 500 W

Length of aperture 14 6 m

Width of aperture 6 71 m

Swath = 1167 km / 630 nm

Target RCS = 200 m^2

Polarization not specified, probably horizontal

PRF = 83 Hz

Uncompressed pulse length = 30μs

Search waveform (waveform/bandwidth) LFM / 1 MHz

Processing incoherent

Design P_d, P_{fa} · P_d = 0 9, P_{fa} = 10^{-6}

Minimum grazing angle = 2 4°

Maximum grazing angle = 30°

10. References

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12. Nomenclature

Report	**Definition**
A	aperture area (m^2)
A_c	clutter area (m^2)
B	instantaneous bandwidth (Hz)
Cd_f	chord, far (km)
Cd_n	chord, near (km)
D	ship displacement (tonnes)
f	frequency (GHz)
h_p	spacecraft height (km)
k	Boltzmann's constant (Ws/K)
k_w	antenna weighting constant
L	aperture length (m)
LPRF	low PRF (Hz)
L_s	system losses (dB)
N_{agile}	number of agile frequencies
N_e	number of antenna elements
N_{hf}	number of hits, far
N_{hn}	number of hits, near
P_{avg}	average power (W)
P_d	probability of detection
P_{fa}	probability of false alarm
PG_f	processing gain, far
PG_n	processing gain, near
RCS	radar cross section (m^2)
R_f	slant range, far (km)
R_n	slant range, near (km)
SS	sea state
SW*n*	Swerling number *n*
T_{dec}	clutter decorrelation time (ms)
T_i	interpulse period (ms)
T_s	system noise temperature (K)
T_{totf}	time-on-target, far (s)
T_{totn}	time-on-target, near (s)
W	aperture width (m)
γ_{bs}	grazing angle, boresight
γ_f	grazing angle, far
γ_n	grazing angle, near
λ	wavelength (m)
ρ_r	range resolution (m)
σ_0	clutter reflection coeft (m^2)
σ_t	target RCS (m^2)

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A Real Aperture, Sidelooking, Ocean Surveillance, Space-based Radar (U)

4 AUTHORS (Last name, first name, middle initial)

Martin, Ronald H

5 DATE OF PUBLICATION (month and year of publication of document) August, 2001	6a NO OF PAGES (total containing information Include Annexes, Appendices, etc) 20	6b NO OF REFS (total cited in document) 8

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A relatively inexpensive space-based radar has be proposed that can provide detection, finger-printing and tracking of ships as small as corvette-sized naval craft The RF power requirements, based on a target of 1000 m2 radar-cross-section, are quite modest, being 157 watts of average power A four-fold increase in RF power to 628 watts would allow detection, in thermal noise at least, of fast patrol boat-sized craft having cross sections down to 250 m2 The problem is not, however, detection in thermal noise but against the sea clutter which may limit the detection of smaller craft to relatively low sea state conditions (sea state 3 or less)

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Space-based radar, Ocean surveillance, Incoherent integration, Radarsat

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