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Informal Technical Report

EDUCTION OF SOLAR GLINTS FROM HE SEA WITH A LINEAR POLARIZER

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Shipboard defense systems employing infrared warning receivers have experienced saturation of threat tection processing circuits due to the signal resulting from solar reflec from the rough sea surface. The saturation has made it necessary to blank the threat sector below the horizon for an azimuth extent of up to +23° either side of the azimuth of the sun. The analysis shows that the use of linear polarizer with a shipboard R warning receiver can be expected to increase number of daylight hours that the sensor can be operated without any blanking, & to narrow the azimuth sector for which blanking is required for low sun angles. The linear → NEXT

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polarizer will be most effective during the middle of the day during the spring, summber, and fall. The unpolarized receiver typically may have to be blanked over a +23° segment of its azimuth search below the horizon nine to eleven hours per day. With a linear polarizer the number of hours for which blanking will be necessary can typically be reduced to six to eight hours per day and the azimuthal extent of the blanking during the remaining hours reduced to $\pm 12^{\circ}$. Further consideration is needed of Navy operational practices and the types and frequencies of occurrence of various sea states encountered at various latitudes, a wave slope model valide for high slopes and wind speeds, and a simulation in which the ship defense system noise, threshold, and spatial resolution are parameters.

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1.0
INTRODUCTION

Shipboard defense systems employing infrared warning receivers have experienced saturation of threat detection processing circuits due to the signal resulting from solar reflection (glints) from the rough sea surface. The saturation has made it necessary to blank the threat sector below the horizon for an azimuth extent of up to ± 23° either side of the azimuth of the sun. It is desirable to reduce the angular extent of the glint region over which saturation occurs. The polarization of visible sunlight reflected from water is a familiar phenomenon, and polarization in the infrared is completely similar [1]. The purpose of this technical note is to discuss the potential effectiveness of using a linear polarizer to reduce the magnitude of the solar glint in the infrared.

The analysis shows that the use of a linear polarizer with a shipboard IR warning receiver can typically be expected to increase the number of daylight hours that the sensor can be operated without any blanking, and to narrow the azimuth sector for which blanking is required for low sun angles. The linear polarizer will be most effective during the middle of the day during the spring, summer and fall. The unpolarized receiver typically may have to be blanked over a ± 23° segment of its azimuth search below the horizon nine to eleven hours per day. With a linear polarizer the number of hours for which blanking will be necessary can typically be reduced to six to eight hours per day and the azimuthal extent of the blanking during the remaining hours reduced to ± 12°.

[1] "Target and Background Characteristics: Analysis and Applications", AFAL-TR-71-239, Report No. #3221-13-P, Willow Run Laboratories of the University of Michigan, October 1971, (Confidential-NFN).

The objective of this analysis has been to investigate the potential for reducing the time and azimuth dimension of the search volume blanked due to solar specular reflection from the sea surface by using a linear polarizer with the receiver. The results are encouraging and thus provide justification for a more in-depth study for the use of polarization techniques to improve the effectiveness of the IR warning receivers in the presence of strong solar reflection from the sea. Further consideration is needed of Navy operational practices and types and frequencies of occurrence of various sea states encountered at various latitudes, a wave slope model valid for high slopes and wind speeds, and a simulation in which the ship defense sensor system noise, threshold, and spatial resolution are parameters.

2.0

BACKGROUND THEORY

Reflection of solar energy from a smooth surface such as water, the windshield of a car, or a metal roof, produces a high intensity signal, commonly referred to as a glint, which can compete with or even mask the signal intensity of a target. Furthermore the reflection of unpolarized energy from the sun by a smooth surface produces a reflected radiance component which can be unpolarized, partially polarized, or completely polarized. The unpolarized condition exists for reflection at normal and grazing incidence, the complete polarization condition occurs for an angle of incidence equal to the Brewster angle, and the partially polarized condition exists for all other angles of incidence. The magnitude of the solar glint can be partially attenuated using a linear polarizer. The amount of attenuation is dependent upon the angle of incidence and the orientation of linear polarizer.

2.1 Reflectance From Water

The Fresnel reflection coefficients for water as a function of incidence angle, θ, are shown in Figure 1 for a wavelength of 4 μm. In this spectral region, the absorption coefficient (imaginary of the index of reflection) is small so that the perpendicular component of reflection goes to zero at the Brewster angle ($\theta_B \approx 53°$ for water at 4 μm).

In general, the energy reflected by a smooth surface from an unpolarized source such as the sun can be thought of as the sum of an unpolarized component and a linearly polarized component. If the surface is assumed to be illuminated by an unpolarized source of unit irradiance and the surface is larger than the incident beam, then the unpolarized component of reflected energy is equal to the parallel reflection coefficient, $r_{\parallel}$. The linear polarized component is equal to one half of the difference between the perpendicular and parallel reflection

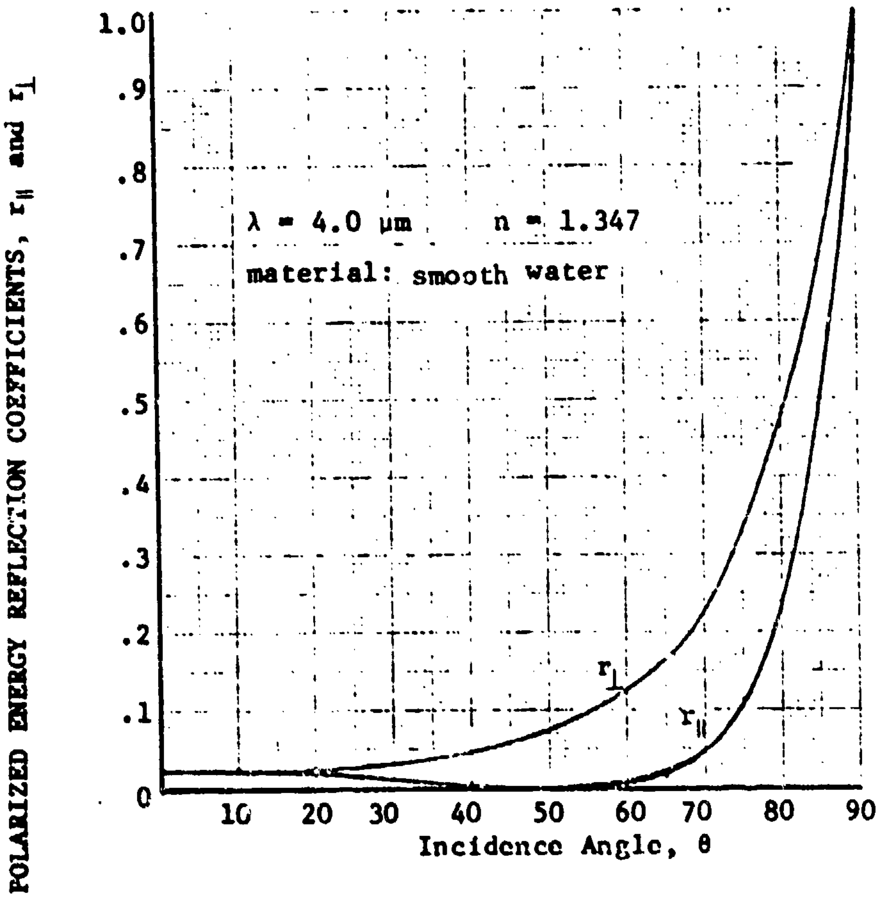

FIGURE 1. FRESNEL REFLECTION COEFFICIENTS FOR WATER AT 4 μm

coefficients, $0.5(r_\perp - r_\parallel)$. A linear polarization analyzer aligned orthogonal to the linearly polarized component will attenuate this component completely, and it will transmit one half of the unpolarized component. Thus the fraction of energy that is transmitted by the linear polarizer, τ_{pol}, is equal to the ratio of one half of the unpolarized component, $0.5r_\parallel$, to the total reflection coefficient, $r = 0.5(r_\perp + r_\parallel)$,

$$\tau_{pol} = \frac{0.5\ r_\parallel}{r} = \frac{r_\parallel}{r_\perp + r_\parallel} \qquad (1)$$

A plot of τ_{pol} is shown in Figure 2. At grazing and normal incidence, $\tau_{pol} = 0.5$ and at the Brewster angle $\tau_{pol} = 0$.

For an unpolarized target viewed against a solar glint at an angle of incidence equal to the Brewster angle, the glint may be completely eliminated and the target power reduced by only a factor of two with a properly oriented linear polarizer. In general, the glint can always be reduced by a factor larger than two, but it must be remembered that the target will always be reduced by a factor of two unless it also produces a partially polarized radiant intensity.

2.2 Sun and View Angle Considerations

Figure 3 describes the geometrical parameters used here. They include the zenith angle to the detector line of sight, θ_d, the solar zenith angle, θ_s, and the relative azimuth angle between the solar direction and the detector line of sight, ϕ. The value of θ_d is typically 89° and this value has been used in the analyses that follow.

For any θ_s, θ_d, and ϕ, the orientation of a surface which will produce a specular reflection can be evaluated. The orientation of such a surface is defined by the zenith angle, θ_n, and azimuth angle, ϕ_n, of the normal to that surface. These two angles are given by the expressions

$$\theta_n = \arc\cos\left\{\frac{\cos\theta_d + \cos\theta_s}{[(\sin\theta_s + \sin\theta_d\cos\phi)^2 + (\sin\theta_d\sin\phi)^2 + (\cos\theta_d + \cos\theta_s)^2]^{\frac{1}{2}}}\right\}$$

Equation (2)

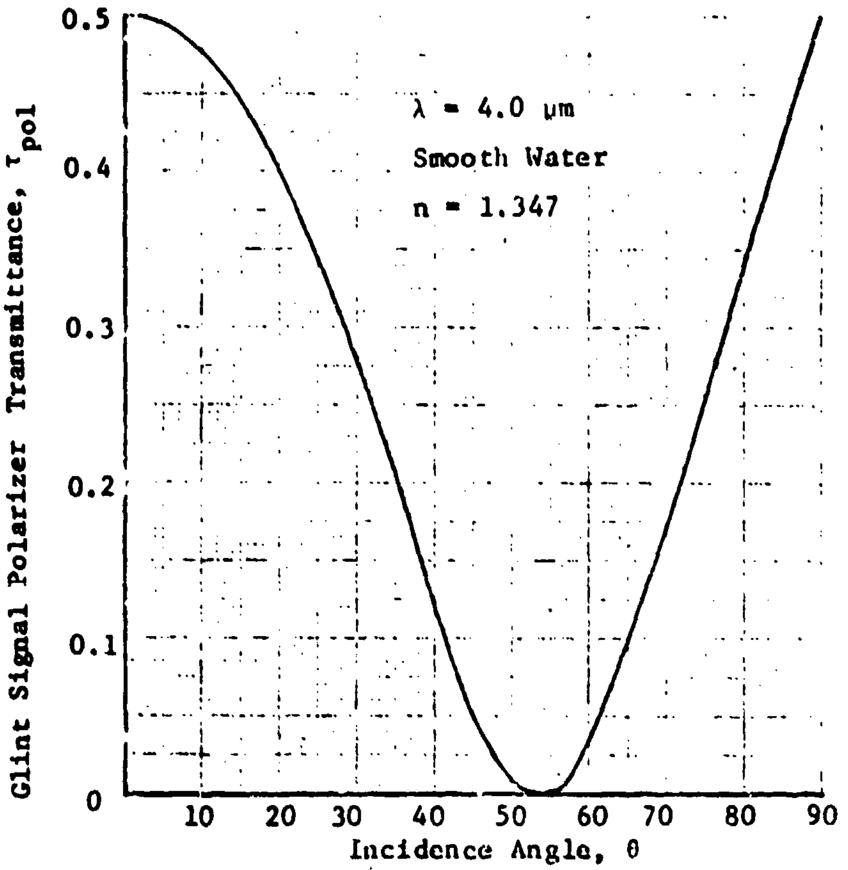

FIGURE 2. GLINT SIGNAL POLARIZER TRANSMITTANCE FOR WATER AT 4 μm

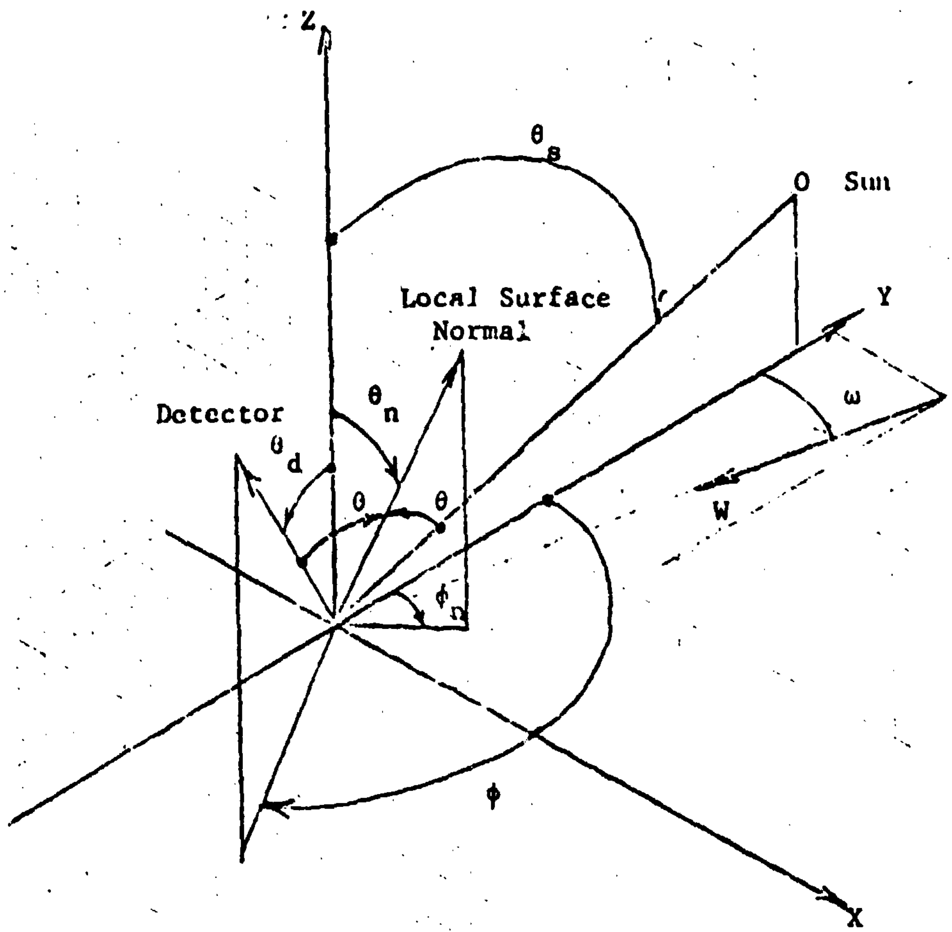

FIGURE 3. SHIP DEFENSE GEOMETRY, θ_d = 89° TYPICALLY

$$\phi_n = \arc\tan \left[\frac{\sin \theta_d \sin \phi}{\sin \theta_s + \sin \theta_d \cos \phi} \right] \tag{3}$$

The local angle of incidence to the surface, θ, is given by the expression

$$\theta = \arc\cos \left\{ \frac{\left[(\sin \theta_s + \sin \theta_d \cos \phi)^2 + (\sin \theta_d \sin \phi)^2 + (\cos \theta_d + \cos \theta_s)^2\right]^{1/2}}{2} \right\} \tag{4}$$

Figure 4 is a plot of the unpolarized and the polarized reflection coefficient of water, sloped to produce specular glints, for $\theta_d = 89°$ for various solar zenith angles, θ_s, and azimuth angles, ϕ. The results are only presented for azimuth angles between 0 and 180° because the results are the same for the 360 to 180° range due to symmetry.

Figure 5 is a plot of τ_{pol} (Equation 1) for $\theta_d = 89°$ for various values of θ_s and ϕ. Both of Figures 4 and 5 show that the highest values of glint extinction occur for moderately high sun positions, i.e. for low values of θ_s. As the sun approaches the horizon, the total signal becomes more unpolarized so that extinction of the glint using a polarizer becomes less effective.

Figure 6 is a plot of the ratio of polarized target signal transmission to polarized glint signal transmission for $\theta_d = 89°$ for various θ_s and ϕ. When this ratio is 1.0, the target signal and the glint signal transmissions are the same and the polarization analyzer is of no benefit. In fact, the use of a polarizer is detrimental in this case since it serves no purpose other than to reduce the system signal-to-noise ratio. A polarizer is least effective when the system is looking right into the sun.

It should be emphasized here, for Figures 4, 5 and 6, that it has been assumed that a reflecting surface with the necessary value of θ_n and ϕ_n exists. Realistic slope distributions of the sea are accounted for in Section 2.3. Figure 7 shows the slope angle, θ_n, required to

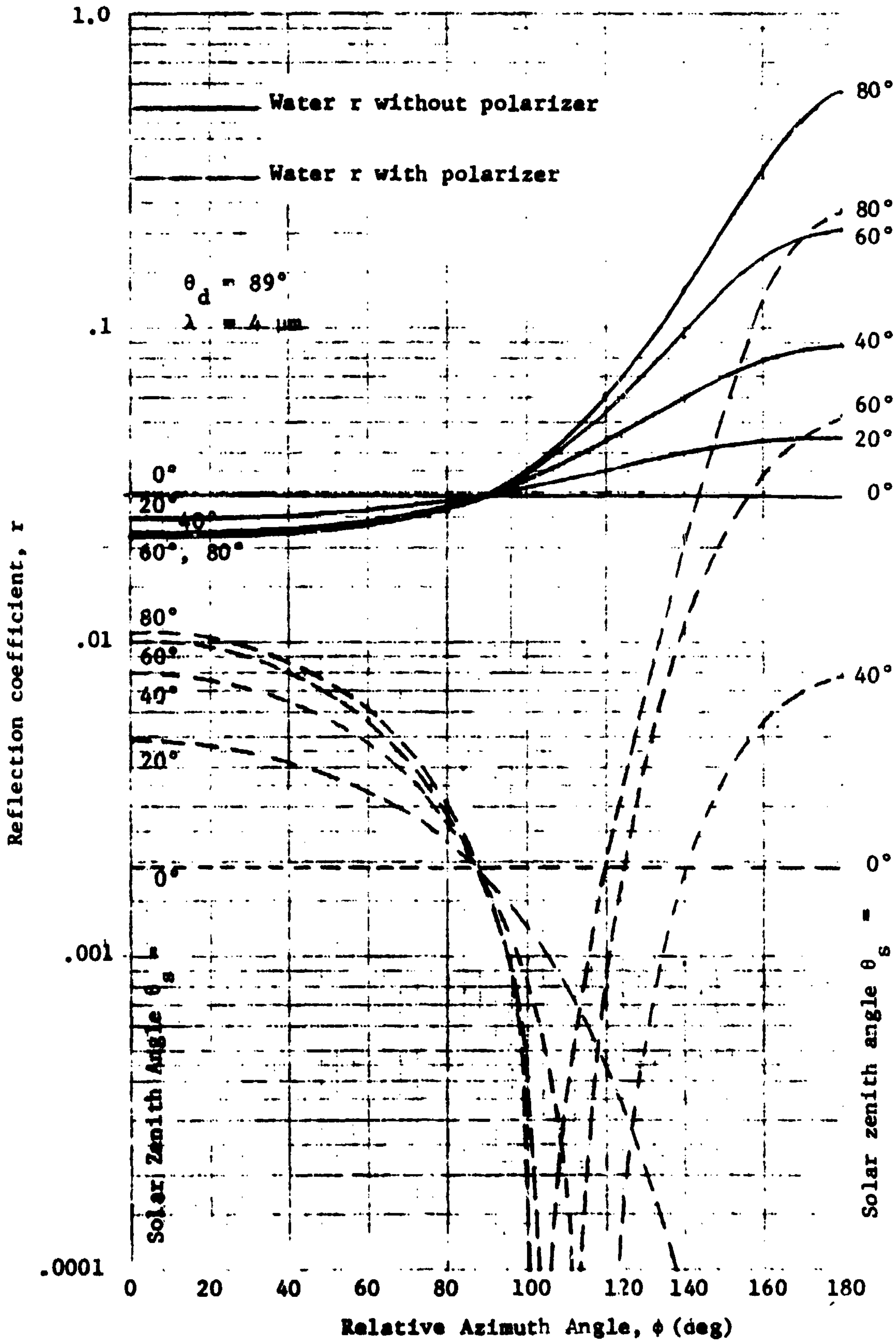

FIGURE 4. GLINT REFLECTANCE WITH AND WITHOUT POLARIZER AT 4 μm FOR SHIP DEFENSE GEOMETRY

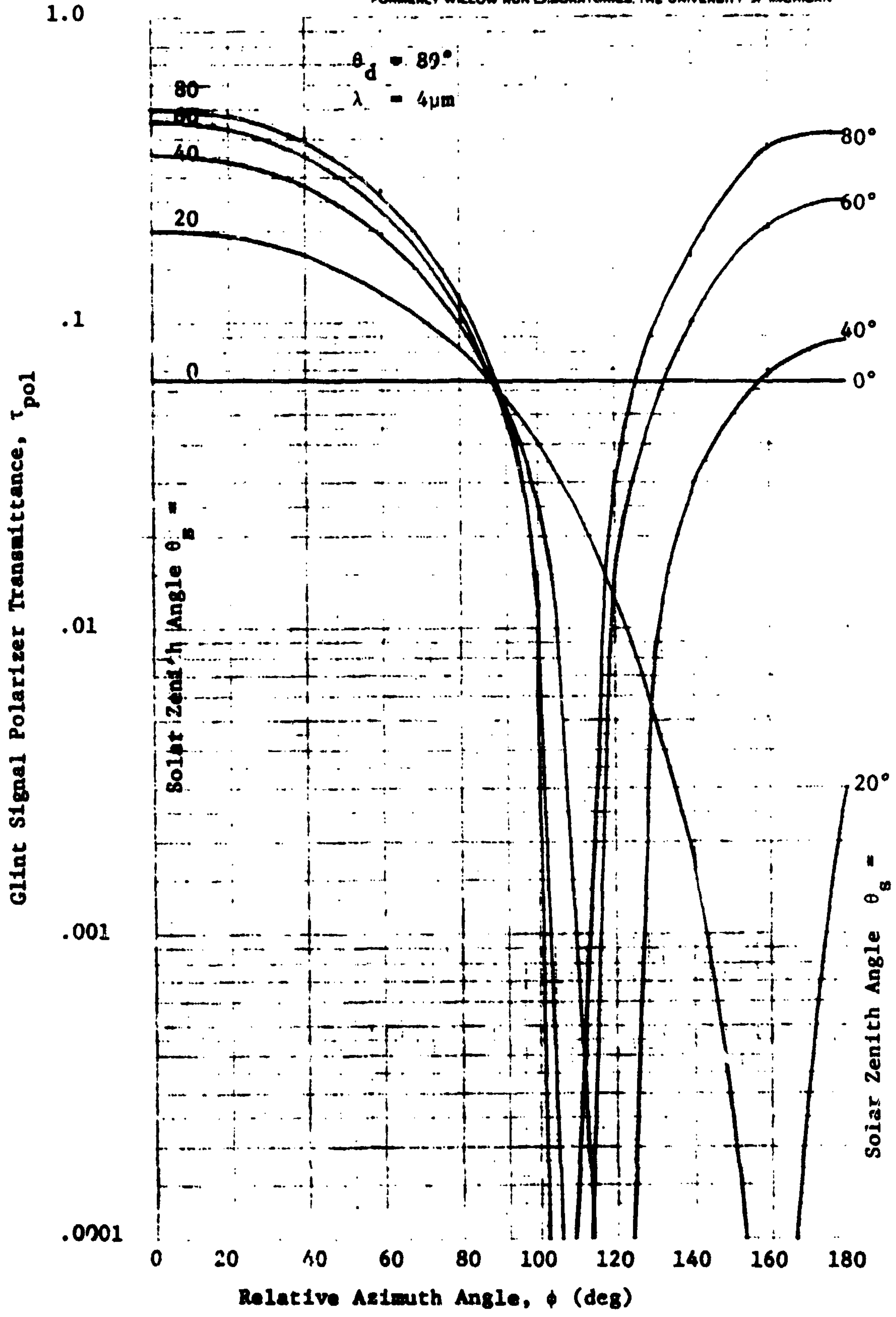

FIGURE 5. GLINT SIGNAL POLARIZER TRANSMITTANCE FOR WATER AT 4 μm FOR SHIP DEFENSE GEOMETRY

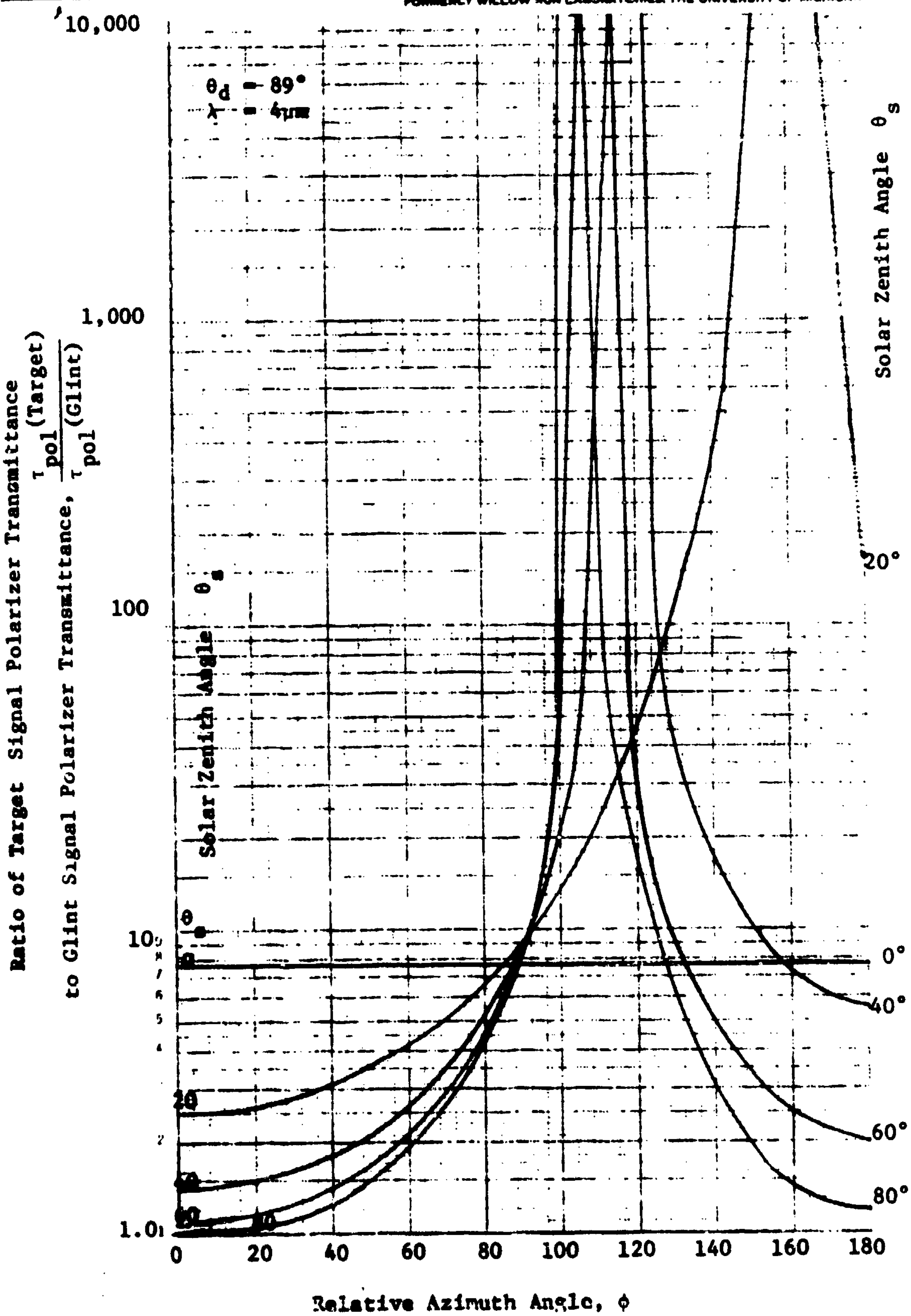

FIGURE 6. RATIO OF TARGET TO GLINT SIGNAL POLARIZATION TRANSMITTANCE AT 4 μm FOR SHIP DEFENSE GEOMETRY

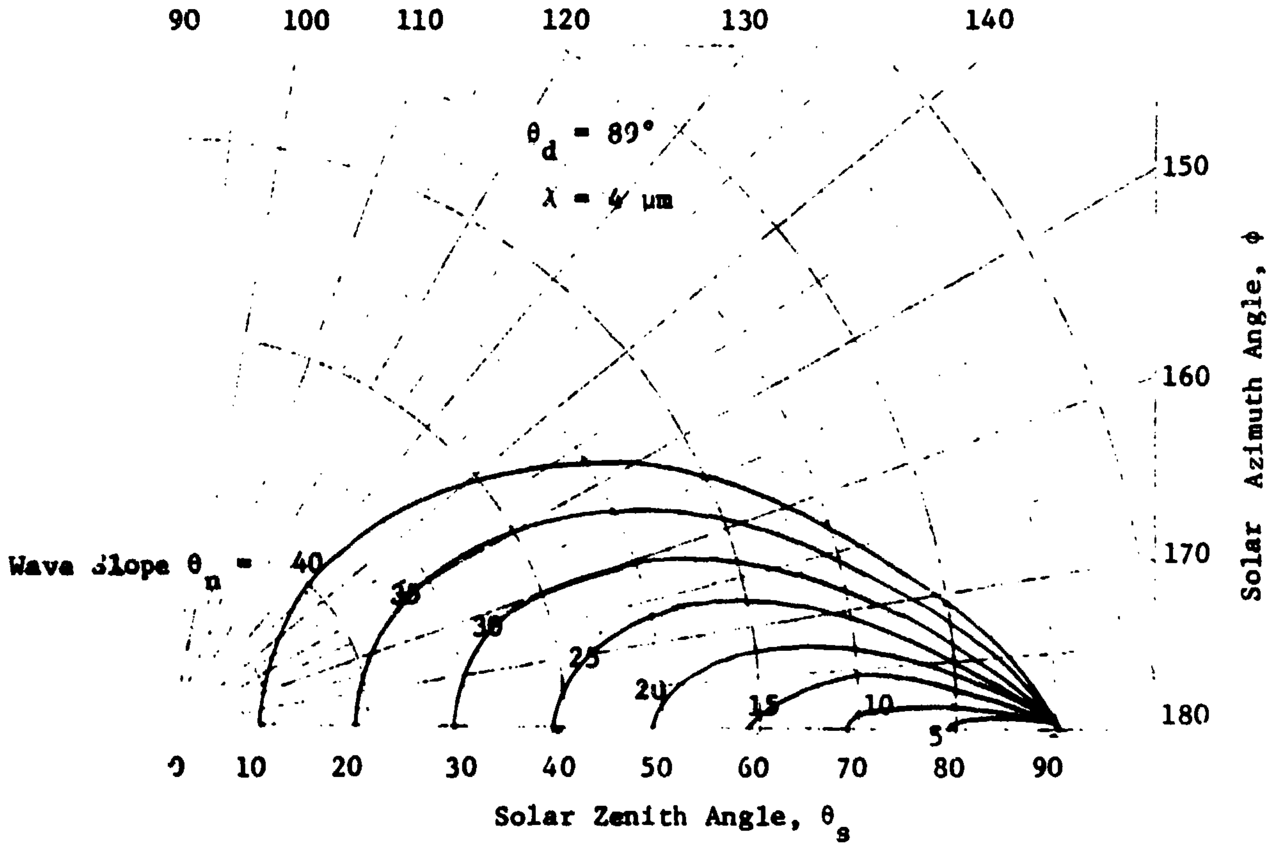

FIGURE 7. POTENTIAL GLINT REGION AS A FUNCTION OF WAVE SLOPE FOR SHIP DEFENSE GEOMETRY

produce a glint for $\theta_d = 89°$ for various solar zenith angles, θ_s, and azimuth angles, ϕ. It is apparent that the surface slope has to be large to produce glints in any geometry other than a forward scattering geometry. To obtain the glint region which is 40° wide in azimuth surface slopes of 30° are required for reasonable solar zenith angles, θ_s.

Figure 7 shows that the sea must be fairly rough to produce a sizable glint region. As the sea surface becomes smooth, the glint region becomes small and occurs only for large solar zenith angles, in which case the glint is reasonably unpolarized and polarization techniques can be expected to be ineffective. Figure 7 also makes it apparent that the full 360° of azimuth need not be considered when evaluating the potential occurrence of glints.

To place better perspective on the usefulness of the polarization concept, Figure 8 presents a combination of Figure 6 and 7 for the azimuth region of interest $130° \leq \phi \leq 180°$. The solid curves in Figure 8 are the target to glint signal ratios of Figure 6 (other values of θ_s have been included). The dashed curves are the potential glint regions of Figure 7. The intersection of the solid and dashed curves define the glint width for a particular solar zenith angle. For example, the intersection of the $\theta_n = 35°$ and $\theta_s = 30°$ curves occurs at $\phi = 150°$; hence with slopes to $\theta_n = 35°$, specular reflections can be expected over an azimuth range 60° in extent, (180 - 150) x 2. The use of a polarizer would provide a target to glint transmission ratio of 40 at $\phi = 150$ and 17 at $\phi = 180$. For calm seas, glints will occur only for sun position near the horizon and the glint extinction by use of a polarization analyzer will then not be effective and may even be detrimental. The horizontal line drawn at 1.414 ($\sqrt{2}$) (see Figure 8) represents the improvement necessary to counterbalance the signal-to-noise loss assuming target or glint noise limited case.

The analysis presented thus far has been qualitative: The potential usefulness of a polarizer increases for larger θ_n (rough sea) and smaller θ_s (high sun). In addition, because the reflectances are smaller for

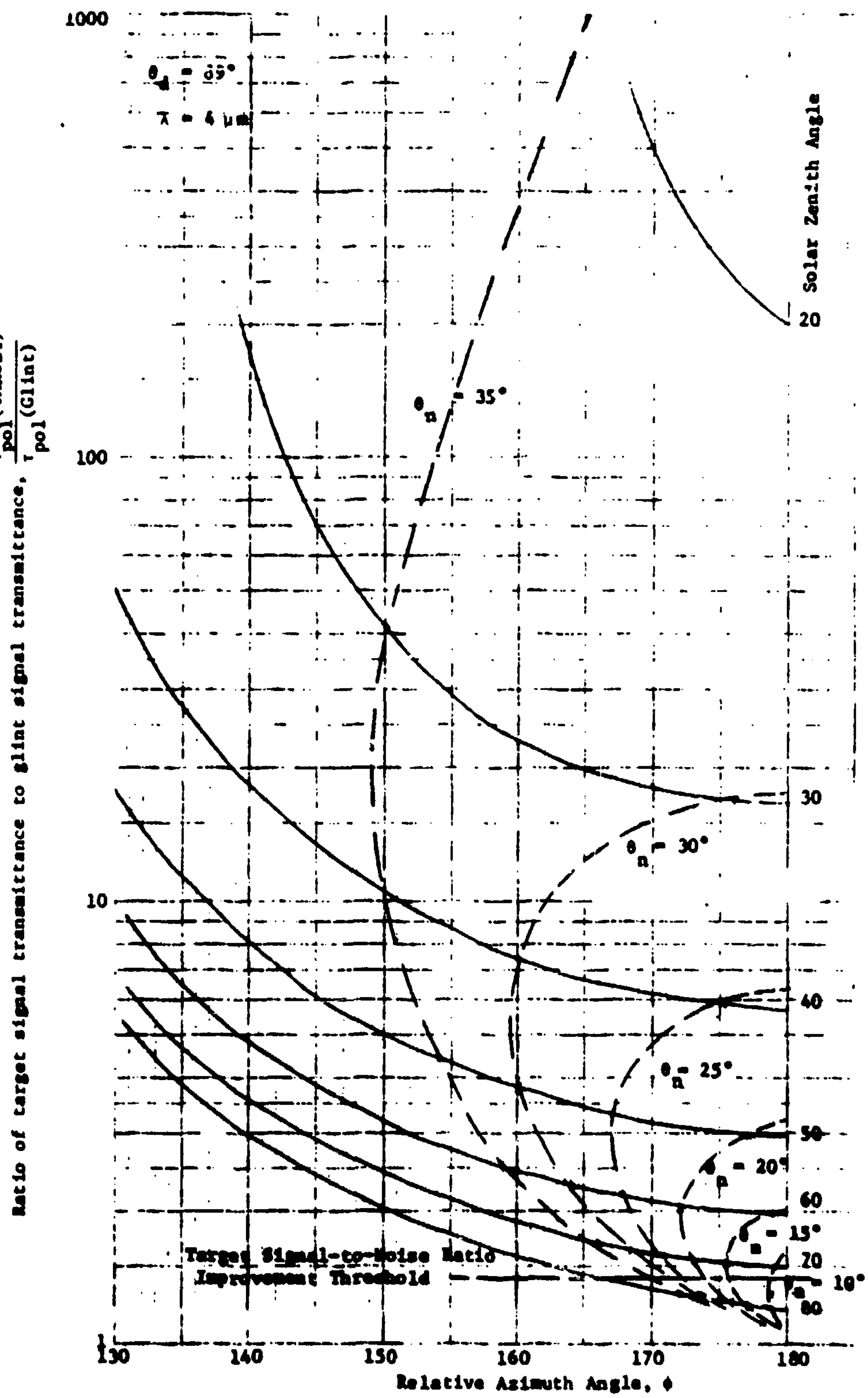

FIGURE 8. DEFINITION OF POTENTIAL GLINT REGION FOR VARIOUS θ_s, θ_n AS A FUNCTION OF φ

small θ_s, there is a better chance that the polarizer will reduce the glint below the sensor threshold. For example, at $\phi = 180$, the reflectance coefficients of potential glint areas for $\theta_s = 80°, 60°, 40°, 20°$ and $0°$ are respectively r = .56, .2, .088, .044, and .029. Thus magnitude of the glints, assuming equal glint areas, are an order of magnitude lower for the $\theta_s = 20°$ as compared to $\theta_s = 80°$. To complete the analysis, data concerning the area of glint surfaces as a function of surface slope are required so that the radiance value associated with the glints can be determined. It does not require a very large glint area to produce a significant glint signal. For example, only 15 cm^2 of surface area necessary to produce a 1 $w \cdot ster^{-1}$ solar glint at 4 μm in a 0.2 μm spectral bandwidth;

$$1\ w \cdot ster^{-1} = r \times A \cos\theta\ L_s\ (4\ \mu m)\ \Delta\lambda \qquad (5)$$

where L_s = spectral solar radiance ($w \cdot cm^{-2} \cdot ster^{-1} \cdot \mu m^{-1}$)

$\Delta\lambda$ = the spectral bandpass

A = the surface area of the glint

θ = the angle of incidence (assumed to be 45°)

r = the reflection coefficient.

At 4 μm $L_s \simeq 16\ w \cdot cm^{-2} \cdot ster^{-1} \cdot \mu m^{-1}$

$r \simeq .03$ at $\theta = 45°$

therefore

$$A = \frac{1}{(.707)\ (.03)\ (16)(.2)} \simeq 15\ cm^2$$

Hence an area 3.9 cm square (a little over 1.5 inches on a side) will produce a radiant intensity of 1 $w \cdot ster^{-1}$ in a 0.2 μm spectral band. Atmospheric attenuation might double the required area. The value of area computed was for a reflectance value that would occur for $\theta_s = 0$,

$\phi = 180$. For larger solar zenith angles, the angle of incidence becomes larger, thus the reflectance is larger, and the area required to produce 1 $w \cdot ster^{-1}$ decreases.

2.3 Realistic Slope Distributions and Glint Reduction with a Polarizer

To become more quantitative in the evaluation of the usefulness of the polarization technique, data relating the probable sea surface slopes is necessary. Several researchers [2, 3, 4] have investigated the distribution of sea surface slopes as a function of wind velocity and direction. The model of Cox and Munk [3] will be used here to evaluate the relative glint surface area as a function of slope and geometry to estimate the amount by which the potential glint region may be reduced using a linear polarizer.

Cox and Munk provide an analytical expression $p(z_x, z_y)$, based on experimental data, which defines the probability for slopes z_x and z_y as a function of wind speed and wind direction. This formulation does not account for shadowing and obscuration amongst waves which will occur for the shipboard observation geometry. Thus the Cox and Munk will predict a value of area which is larger than will occur.

$$p(z_x,z_y) = (2\pi\sigma_c\sigma_u)^{-1} e^{-1/2(\xi^2 + \eta^2)} \Big\{ 1 - 1/2\, C_{21}(\xi^2 - 1)\, \eta - 1/6\, C_{03}(\eta^3 - 3\eta) + \frac{1}{24} C_{40}(\xi^4 - 6\,\xi^2 + 3) + 1/4\, C_{22}(\xi^2 - 1)\,(\eta^2 - 1) + \frac{1}{24} C_{04}(\eta^4 - 6\,\eta^2 + 3) \Big\} \qquad (6)$$

[2] C. Cox and W. Munk, "Measurement of Roughness of the Sea Surface from Photographs of the Sun's Glitter", J.O.S.A. Vol. 44, No. 11, November 1954, pp. 838-850.

[3] A. L. Schooley, "Relationship between Surface Slope, Average Facet Size, and Facet Flatness Tolerance of a Wind-Disturbed Water Surface", J.G.R. Vol. 66, No. 1, January 1961, pp. 157-162.

[4] J. Wu, "Slope and Curvature Distribution of Wind-Dispatched Water Surface", J.O.S.A. Vol. 61, No. 7, July 1971, pp. 852-858.

where $z_x = -\tan\theta_n \sin(\phi_n - \omega)$

$$z_y = -\tan\theta_n \cos(\phi_n - \omega)$$

$$\xi = \frac{z_x}{\sigma_c}$$

$$\eta = \frac{z_y}{\sigma_u}$$

$$\sigma_c^2 = 0.003 + 1.92 \times 10^{-3}\ W$$

$$\sigma_u^2 = 0.000 + 3.16 \times 10^{-3}\ W$$

$$C_{21} = 0.01 - 0.0086\ W$$

$$C_{03} = 0.04 - 0.033\ W$$

$$C_{40} = 0.40$$

$$C_{22} = 0.12$$

$$C_{04} = 0.23$$

W = wind speed (m/sec)

ω = azimuth of wind vector from the sun (Figure 3)

Expression 6 for $p(z_x, z_y)$ provides a reasonable estimate of slope distributions within limits defined by $|\xi| \leq 2.5$ and $|\eta| \leq 2.5$. For a given wind speed, W, and wind direction, ω, these limits define a range of θ_n and ϕ_n for which the Cox and Munk distribution is valid. The range of θ_n along wind, with $(\phi_n - \omega) = 0$ and 180, and cross wind, with $(\phi_n - \omega) = 90$, and 270, are shown in Figure 9 for various W. To use the slope distributions of Cox and Munk for θ_n as large as 30°, we should limit our analyses to cross winds of ≤ 17 m/sec and along winds of ≤ 27 m/sec.

For the glint reduction analyses that follows, the following assumptions have been made:

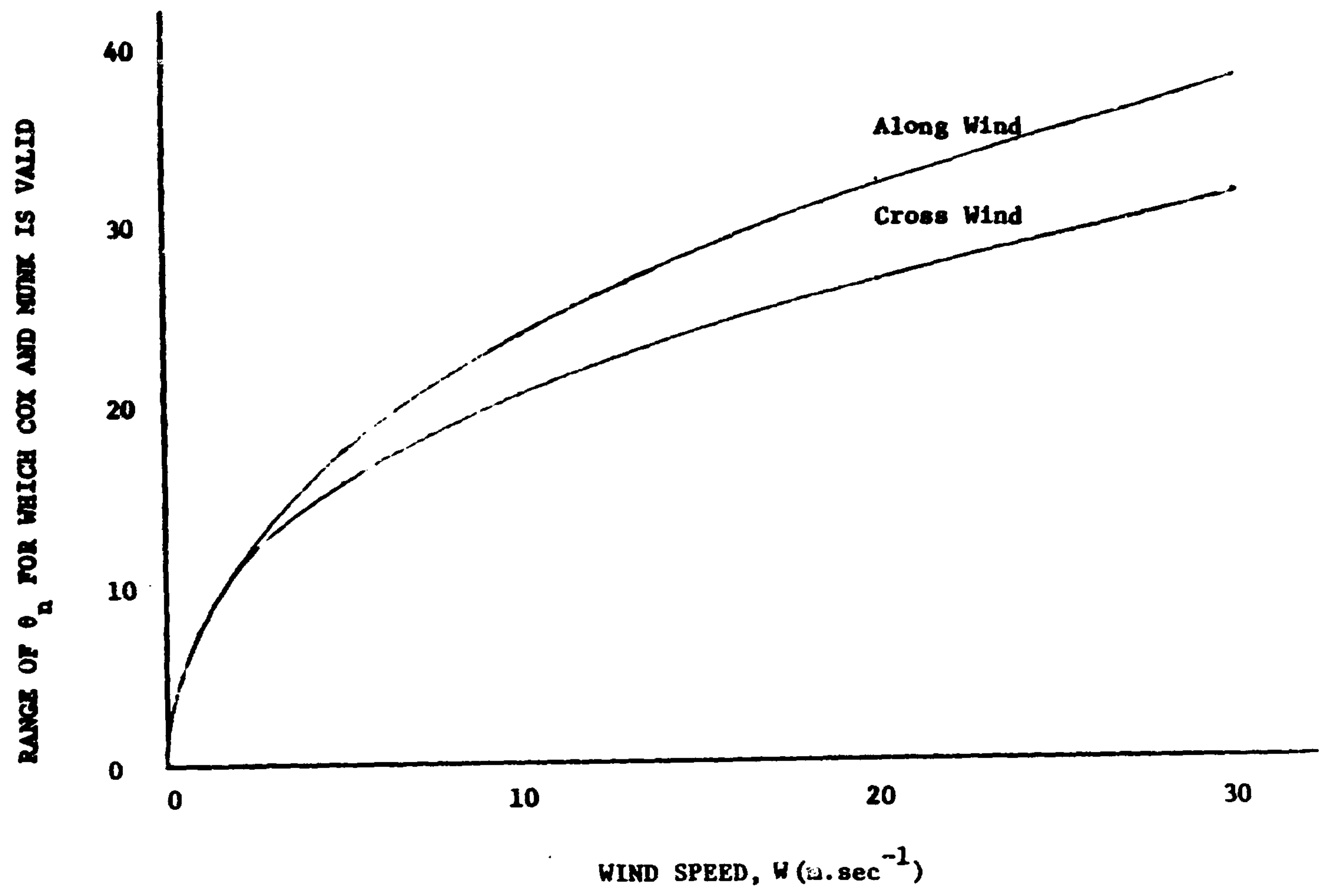

FIGURE 9. RANGE OF θ_n FOR WHICH COX AND MUNK IS VALID

$(\phi_n - \omega) = 180 \Longrightarrow$ the wind direction is always aligned with the azimuth direction of the reflecting facet.

and $W = 16$ m/sec $\Longrightarrow$ the $p(z_x, z_y)$ are valid for all slopes from $0°$ to $30°$ with $\theta_d = 89°$, this corresponds to glints produced with $\theta_s \geq 30$.

With the slope distribution $p(z_x, z_y)$, Cox and Munk show that the radiance from the sun, reflected by the water, is

$$L = \frac{p(z_x, z_y)\ r(\theta)\ E}{4 \cos^4(\theta_n) \cos(\theta_d)} \tag{7}$$

where E is the solar irradiance normal to the sun's rays. Glints tend to saturate ship defense sensors within an angular range of approximately $\pm$ 20°. For purposes of illustration we will assume that the threshold value of sun-glint radiance with $\theta_d = 89°$, L^t, occurs at $\theta_s = 40°$ and $\phi = 160°$ looking into a 16 m/sec wind. L^t can be determined from Equation 7, and then the conditions for which $L \leq L^t$ using a polarizer (range of azimuth angles, ϕ, for each solar zenith, θ_s) can be determined. This is done by determining the value of ϕ for each θ_s for which

$$L(\theta_s, \phi) \leq L^t(40°, 160°)$$

or equivalently

$$\tau_{pol}(\phi, \theta_s) \frac{p(0, z_y)\ r(\theta)}{\cos^4(\theta_n)} \leq \frac{p(0, z_y^t)\ r(\theta^t)}{\cos^4(\theta_n^t)} = 0.0311 \tag{8}$$

The right hand side of the inequality has been evaluated as follows:

$\theta_n^t = 30.0235°$ from Equation 2 with $\theta_s^t = 40°$, $\phi^t = 160°$, $\theta_d = 89°$

$\theta^t = 63.0984°$ from Equation 4 with $\theta_s^t = 40°$, $\phi^t = 160°$, $\theta_d = 89°$

$r(\theta^t) = 0.08°$ from Figure 4 and defined by $\theta_s^t = 40°$, $\phi^t = 160°$, $\theta_d = 89°$

$z_y^t = \tan \theta_n^t = 0.5779$

$p(0, z_y^t) = 0.2183$

The left hand side has been evaluated as a function of ϕ for various θ_s with $\theta_d = 89°$ ($\tau_{pol}(\phi, \theta_s)$ can be determined from Figure 5). Shown in Figure 10 are the values of ϕ for each θ_s for which $L \leq L^t$. For example with $\theta_s = 50°$, and in fact for all $\theta_s \leq 52°$ $L \leq L^t$ for all ϕ. At $\theta_s = 60°$, $L \leq L^t$ for $\phi \leq 168°$; at $\theta_s = 70°$, $L \leq L^t$ for $\phi \leq 169°$ etc. As θ_s approaches 90°, the range of ϕ for which $L \leq L^t$ about $\phi = 180°$ becomes very small, not so much because of the polarizer but because the angular extent of the glint about $\phi = 180°$ is small at $\theta_s = 90°$ anyhow.

The data in Figure 10 show that whenever the sun zenith angles θ_s is less than 30°, for the W = 16 m/sec sea state considered, the unpolarized receiver does not have to be blanked because the intensity of the sunglint is below the threshold value L^t. Typically the sun zenith θ_s is less than 30° for only one to two hours per day, and then only during the summer months at the midlatitudes. Figure 10 also shows that, under the same wind condition, the polarized receiver does not need to be blanked whenever the sun zenith angle θ_s is less than about 50°. Typically the sun zenith θ_s is less than 50° for a period lasting about three hours longer than θ_s less than 30°. This means a longer time window in which an IR shipboard warning receiver can give complete azimuthal coverage. Further, Figure 10 shows that the azimuth sector below the horizon which needs to be blanked for the lower sun elevation angles (larger θ_s) can be reduced from approximately $\pm$ 23° to $\pm$ 12°.

The result of the fact that glints can be reduced to a level lower than L^t whenever $\theta_s \leq 50°$ is shown in Figure 11. At 40°N latitude, $\theta_s \leq 50°$ for more than 40% of the daylight hours from early April until mid-September. Hence during these months glint levels can be reduced by

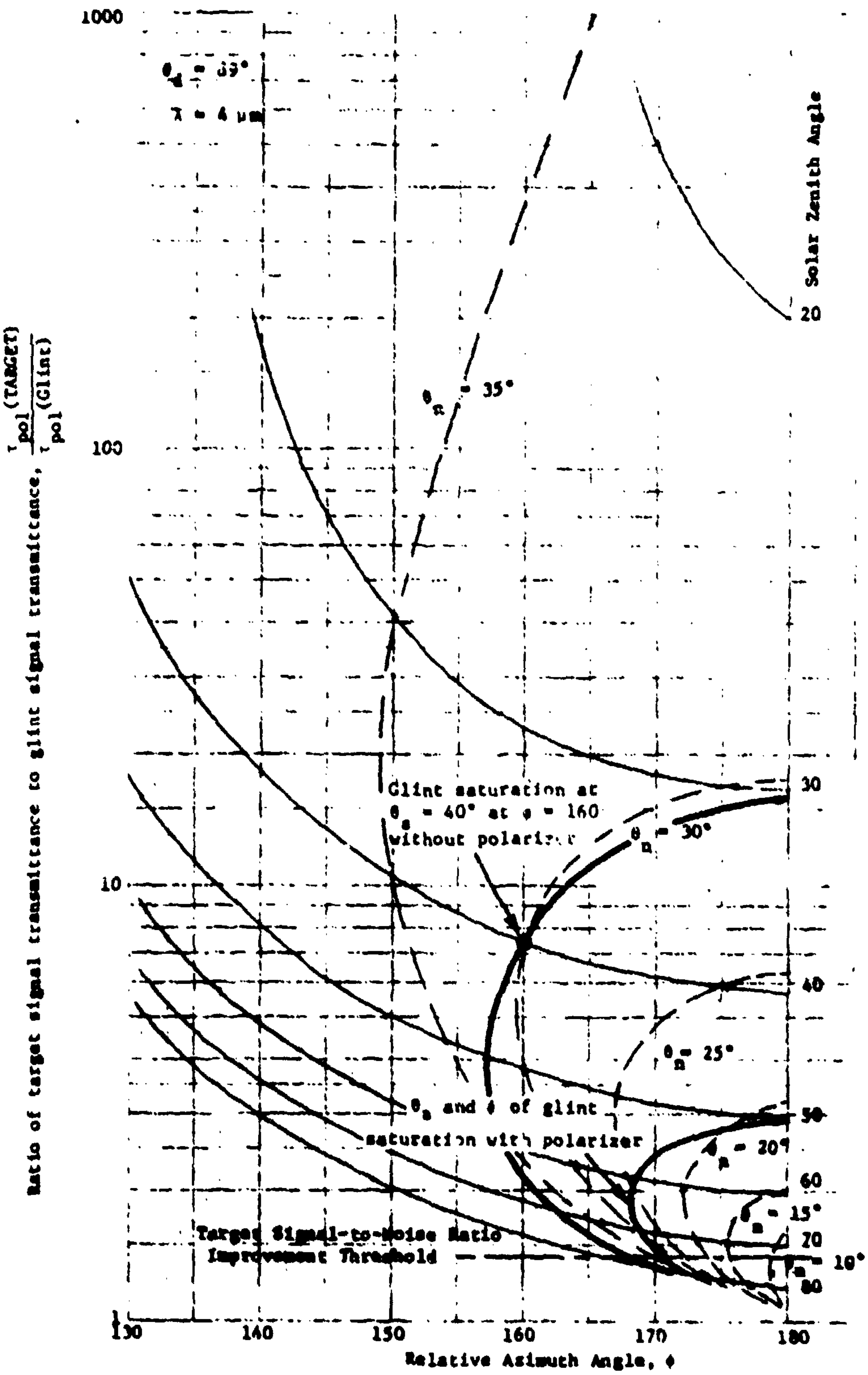

FIGURE 10. DEFINITION OF θ_s AND φ OF GLINT SATURATION WITH POLARIZER

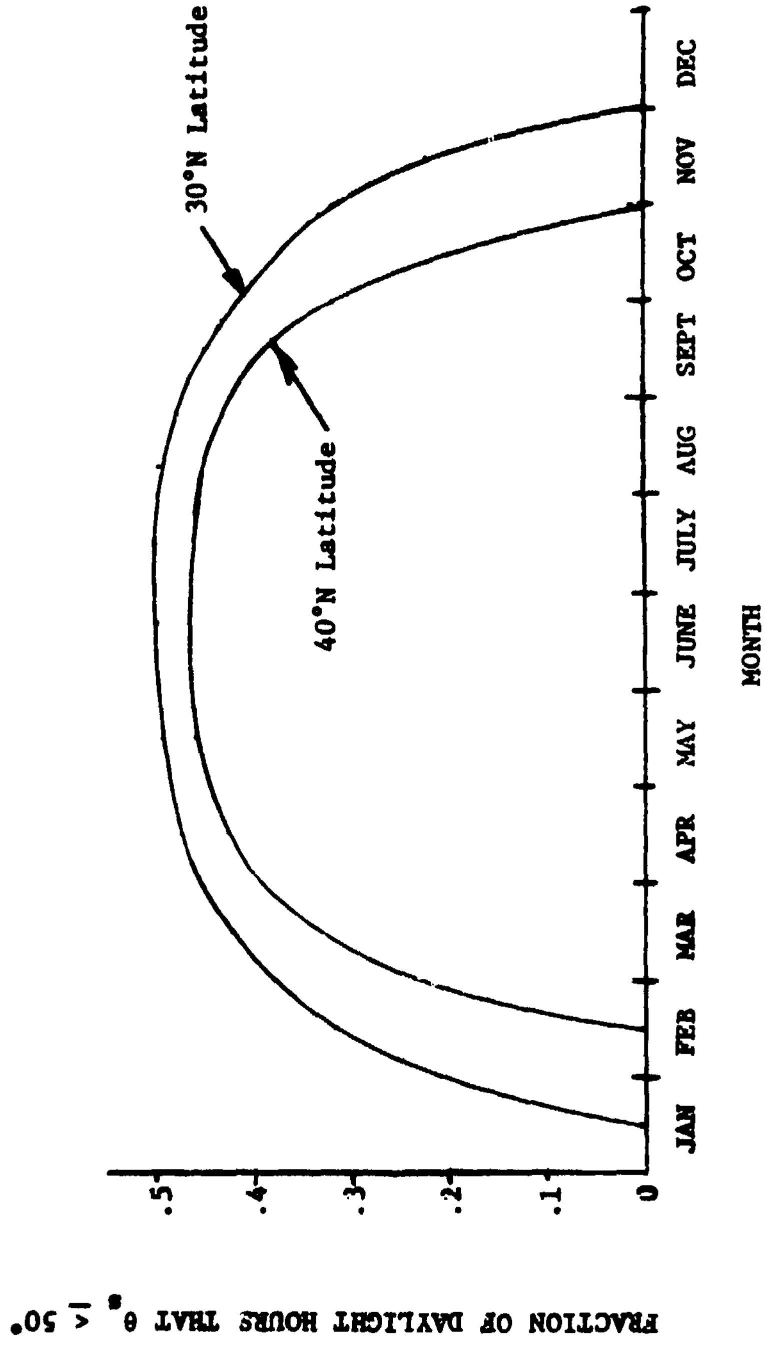

FIGURE 11. FRACTION OF DAYLIGHT TIME THAT THE ZENITH ANGLE OF THE SUN IS LESS THAN 50° FOR 30°N AND 40°N LATITUDE

using a polarizer to below the threshold level L^t during 40% of the daylight hours; the region for blanking can be narrowed from $\pm$ 23° to no more than $\pm$ 12° the rest of the time.

The results presented here show that the potential glint area can be significantly reduced using a polarizer; however, a rather special case was evaluated and assumptions were made concerning the system parameters. The results presented here however are encouraging and should provide justification for a more in depth study of the feasibility of using a polarizer to extinguish glints. If further study is undertaken, consideration should be given to the following:

- A realistic simulation of the effects of wind relative to viewing geometry;
- A wave slope model which is valid for high slopes and wind speeds; and
- A simulation in which the ship defense system noise threshold and spatial resolution are parameters.

3.0

HARDWARE CONSIDERATIONS

It was shown in Section 2 that there is merit to considering polarization techniques to reduce the effects of solar glints. Here the implementation of such techniques is briefly discussed to provide some insight into the type of system modification that are required if polarization techniques are used.

Since the polarization content of the solar glint is linear plus random polarization, a linear polarizer is required. Maximum extinction of the solar glint is achieved when the linear polarization analyzer is aligned orthogonal to the linear polarization component of the solar glint. The linear polarization of the solar glint varies with solar elevation, θ_s, and azimuth angle, ϕ. The plane of polarization is defined by a polarization azimuth angle, α [5]. The polarization azimuth angle is $\alpha = 0$ looking straight into the sun where the polarization is horizontal. In general the polarization is perpendicular to the plane defined by the sun - glint - viewer plane. α will be CW in the glint to the left of the sun, CCW to the right. Figure 12 shows the behavior of the polarization angle, α, as a function of solar azimuth, ϕ, and solar zenith angle, θ_s, for the azimuth angles of interest. The hatched region delineates the angular range of θ_s and ϕ where polarization techniques have been shown to be most effective (the region defined by $\theta_s \leq 53°$ and $\theta_n \leq 30°$). In this region polarization azimuth angle varies between 0 and 23°. The average angle is on the order of 8 to 9°.

To obtain maximum glint extinction, the polarization analyzer would have to vary as a function azimuth angle for a given solar zenith angle. However, since a polarization analyzer extinction varies as the cosine squared of the angle between the axis of polarizer and the linear polarization component, a linear polarizer with its polarization axis oriented

[5] Shurcliff, William A., "Polarized Light Production and Use", Harvard University Press, Cambridge, Massachusetts, 1966.

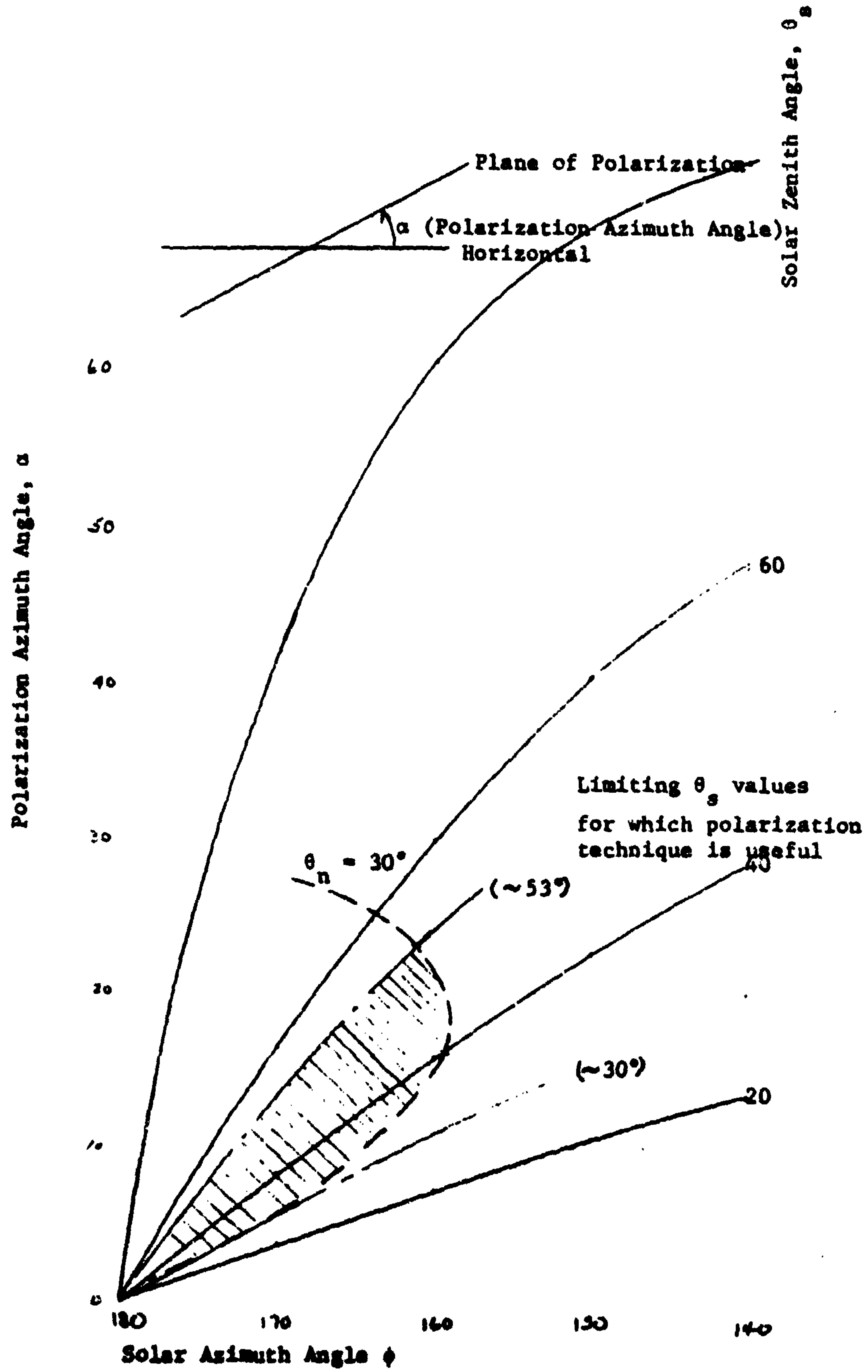

FIGURE 12. POLARIZATION AZIMUTH AS A FUNCTION OF SOLAR GEOMETRY

vertically would, on the average, be 98% as effective as an analyzer optimally oriented. Therefore, a system using a polarization analyzer oriented vertically, covering the necessary field-of-view, will perform almost as well as the optimum system and of course will be much easier to implement.

The field-of-view for which the polarizer is needed is small. The polarizer would be needed over $\sim 2°$ in elevation and $\sim 46°$ in azimuth to effectively reduce the solar glint. The elevation range should be slightly above the horizon to about 2° below the horizon; the azimuth range should be centered $\pm$ 23° about the azimuth direction to the sun. The elevation aspect could remain fixed, but provision would have to be made to move the polarization analyzer in azimuth to off-set ship maneuvers relative to the sun.