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The Use of Active Microwave Sensors in Search and Rescue Operations

July 1986

Prepared for:

NASA Headquarters
Office of Space Science Applications
Code EC, John Kiebler
Washington, D.C. 20546

Contract No. NASW - 3973

Prepared by Tom Tillotson

SYSTEMATICS GENERAL CORPORATION
COMMUNICATIONS AND ELECTRONICS DIVISION

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ABSTRACT

This report studies the possibility of utilizing low-orbit active microwave sensors in Search And Rescue (SAR) operations to detect and positionally locate scenes of distress. Particularly this report addresses the use of a scanning type system, i.e. rotating a highly directional antenna as opposed to a more complex synthetic aperture type system. Targets for this system will be passive reflectors, not active tranmitters like EPIRBs; reflectors which could be easily stowed, require little to no maintenance, could be quickly erected and can be more affordable than battery powered alternatives. Presented are parametric analyses to determine the required antenna gains and reflector areas for various frequencies and orbit altitudes. Also, major issues are raised as well as indicating areas requiring further study.

The Use of Active Sensors in Search and Rescue Operations

A system has been proposed whereby active microwave sensors (radar) in low orbit may be used in Search and Rescue (SAR) operations to detect distress signals. Distress signals will be in the form of abnormally high reflectivity due to the presence of a passive reflector. If a sufficient resolution can be obtained distress signals can be indicated by specific reflector arrangements.

Calculating the Total Power Received at Low Orbit from Earth Scattering and Passive Reflecting

Figure 1 shows the geometry for the proposed low orbiting active sensor system. The total power received (less background radiation) can be calculated from the following equation:

$$P_r = \left[\frac{P_t G_t}{4\pi R^2}\right] \left[\frac{A_{eff}}{4\pi R^2}\right] \left[\sigma A_{footprint} + \sigma'_{target}\right] \tag{1}$$

where:

P_r = the power received at the output of the receiving antenna.

P_t = the transmit power at the input of the transmit antenna.

G_t = the gain of the transmit antenna over an isotropic radiator.

A_{eff} = the effective area of the receiving antenna.

R = the slant range distance to the sensor resolution cell.

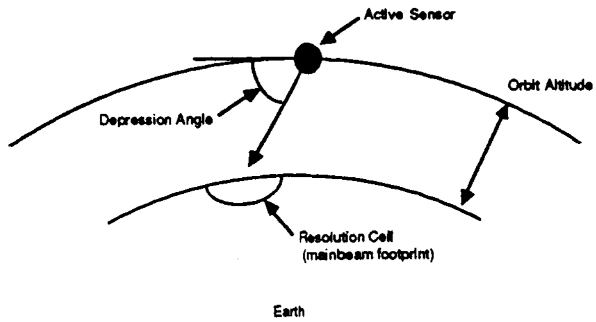


Figure 1. Sensor Geometry

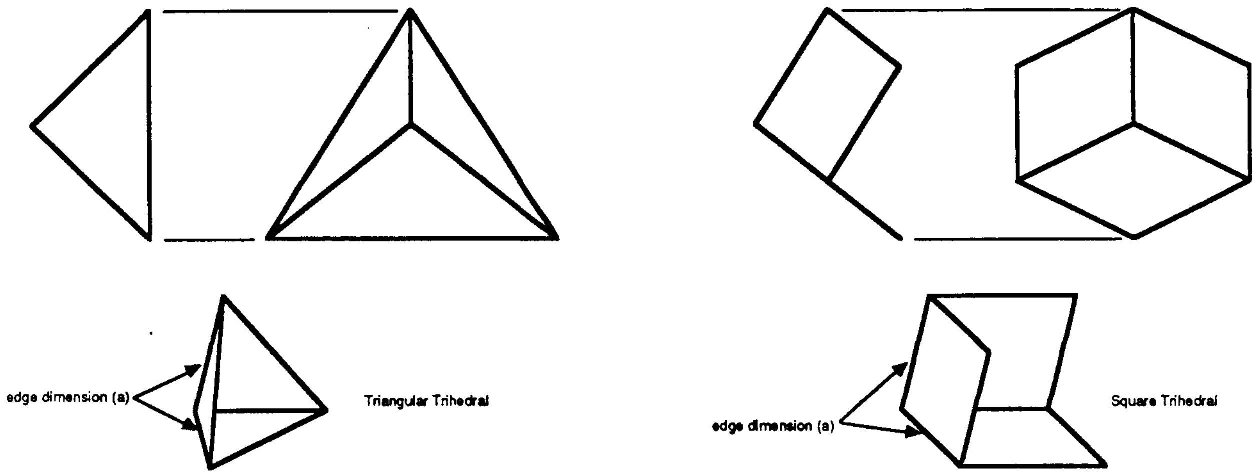


Figure 2. Trihedrals

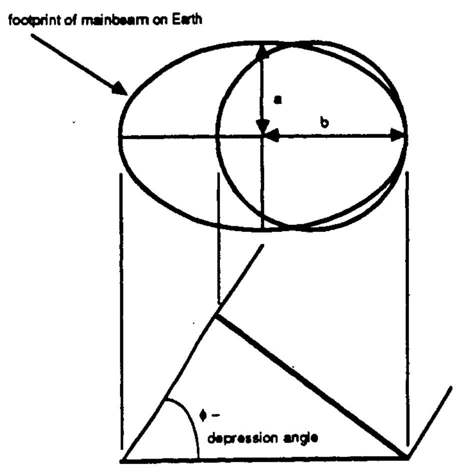


Figure 3. Mainbeam Footprint Area Geometry

$A_{footprint}$ = the area of the antenna's -3 dB contour on the surface of the earth (resolution cell).

σ = the "scattering coefficient" which represents the equivalent scattering cross section per unit area of land.

σ'_{target} = the "scattering cross section" of a passive relfector which represents the equivalent cross section of a conducting sphere which would return an echo equal in strength from the target in question.

The relationship between σ and σ' is:

(2) $\sigma' = (\sigma)\cdot$(area of land in view).

A target (passive reflector) can be defined in terms of its effective area. The effective area is the area of an equivalent flat conducting plate oriented so as to be perpendicular to the direction of the incident radiation which and returns an echo equal in strength as from the target in question. The scattering cross section, σ', is related to the equivalent flat plate area (A_{fp} = ab where a and b are the edge dimensions) by:

(3) $$\sigma' = \frac{4\pi A_{fp}^2}{\lambda^2}$$

where λ is the wavelength at which measurements are made.

A reflector does not have to be a conducting sphere or flat plate. An efficient, broadband, broadbeam reflector is the trihedral or corner reflector (figure 2). The planes forming the trihedral are perpendicular to one another, hence the name corner reflector.

For a triangular trihedral reflector the equivalent flat plate area is:

(4) $$A_{fp} = a^2/\sqrt{3}$$

where (a) is the length of the edge from the vertex to opening. For a square trihedral reflector:

(5) $$A_{fp} = \sqrt{3}\, a^2$$

where (a) is the length of the edge from the vertex to opening.

Equation (1) is the sum of the contributions of normal backscatter and the additional reflected energy from a passive reflector. In the equation ($\sigma A_{footprint}$) represents reflection and scattering of incident radiation due to normal backscatter and (σ'_{target}) represents the additional reflected energy from a passive reflector.

Consider first the contribution to the received power due to normal backscatter:

(6) $$P_r = \left[\frac{P_t G_t}{4\pi R^2}\right] \left[\frac{A_{eff}}{4\pi R^2}\right] \left[\sigma A_{footprint}\right]$$

The effective area can be written as:

(7) $$A_{eff} = G \frac{\lambda^2}{4\pi}$$

where it is assumed the same antenna is used for both receive and transmit and has gain (G).

Utilizing the geometry of figure 3 the area of the sensor's -3 dB footprint can be approximated by the area of an ellipse formed by the intersection of a cylinder and a plane where the minor and major axes are:

(8) $$a = R \frac{\theta}{2} = \frac{\text{resolution}}{2}$$

(9) $$a = R \sqrt{\frac{30{,}000}{G}} \frac{\pi}{180} \frac{1}{2}$$

(10) $$b = \frac{a}{\cos \phi}$$

where:

(11) $\theta =$ the -3dB beamwidth of the transmit/receive antenna = $\sqrt{\frac{30{,}000}{G}}$ degrees.

and $\phi =$ the depression angle measured from the orbit tangent to the antenna boresight.

The area of the footprint is then given by:

(12) $$A_{footprint} = \pi\ a\ b = \frac{\pi\ a^2}{\cos \phi}$$

(13) $$A_{footprint} = \frac{\pi}{\cos \phi} \left[R^2 \frac{30{,}000}{G} \frac{\pi^2}{180^2} \frac{1}{2^2} \right]$$

(14) $$A_{footprint} = \frac{\pi^3\ R^2\ 0.2315}{G \cos \phi}$$

Substituting equations (7) and (14) into equation (6) yields:

(15) $$P_r = \left[\frac{P_t G_t}{4\pi R^2} \right] \left[\frac{G\,\lambda^2}{4\pi} \frac{1}{4\pi R^2} \right] \sigma \left[\frac{\pi^3\ R^2\ 0.2315}{G \cos \phi} \right]$$

(16) $$P_r = \left[\frac{P_t G_t}{4\pi R^2} \right] \sigma \left[\frac{\lambda^2\ \pi}{69 \cos \phi} \right]$$

if $\theta = \sqrt{27{,}000/G}$ then:

$$(17) \qquad P_r = \left[\frac{P_t G_t}{4\pi R^2}\right] \sigma \left[\frac{\lambda^2 \pi}{77 \cos\phi}\right]$$

An alternate method of calculation using a different form of the equation for antenna effective area and mainbeam beamwidth yields a slightly different result. Assuming the effective area to be:

$$(18) \qquad A_{eff} = \eta \frac{\pi D^2}{4}$$

where (h) is the antenna efficiency and (D) is the physical antenna diameter, and the beamwidth to be:

$$(19) \qquad \theta = \frac{71\lambda}{D}$$

it then follows by similar calculations that:

$$(20) \qquad A_{footprint} = \frac{\pi^3 R^2 \lambda^2 0.0389}{D^2 \cos\phi}$$

and:

$$(21) \qquad P_r = \left[\frac{P_t G_t}{4\pi R^2}\right] \sigma \left[\frac{\eta \pi \lambda^2}{41.7 \cos\phi}\right]$$

If $\eta = 65\%$ then:

$$(22) \qquad P_r = \left[\frac{P_t G_t}{4\pi R^2}\right] \sigma \left[\frac{\pi \lambda^2}{64 \cos\phi}\right]$$

or if $\eta = 55\%$ then:

$$(23) \qquad P_r = \left[\frac{P_t G_t}{4\pi R^2}\right] \sigma \left[\frac{\pi \lambda^2}{76 \cos\phi}\right]$$

Equation (23) differs from equation (16) in that it allows the antenna efficiency to be used more directly in the calculations. A ten percent increase in the antenna efficiency from 55% to 65% results in an 18% increase in the received power, or about 0.7 dB.

Since $[\sigma A_{footprint} + \sigma']$ represents the portion of the incident energy reflected back towards the source we can say that to receive an amount of power 'p' percent above the normal backscatter would require that:

$$(24) \qquad [\sigma A_{footprint} + \sigma'] = [1+p][\sigma A_{footprint}]$$

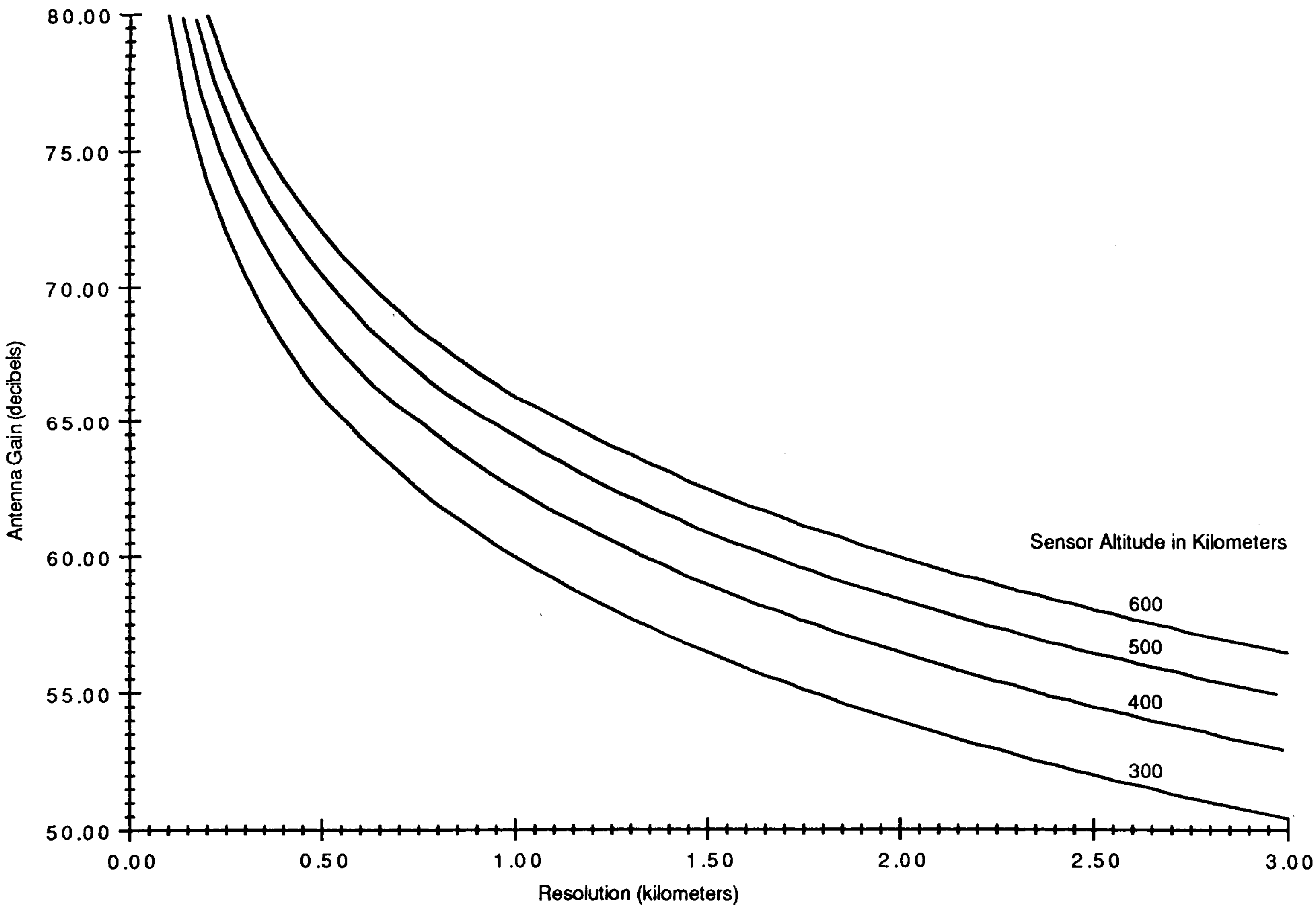
or

$$(25) \qquad \sigma' = p \sigma A_{footprint} \cdot$$

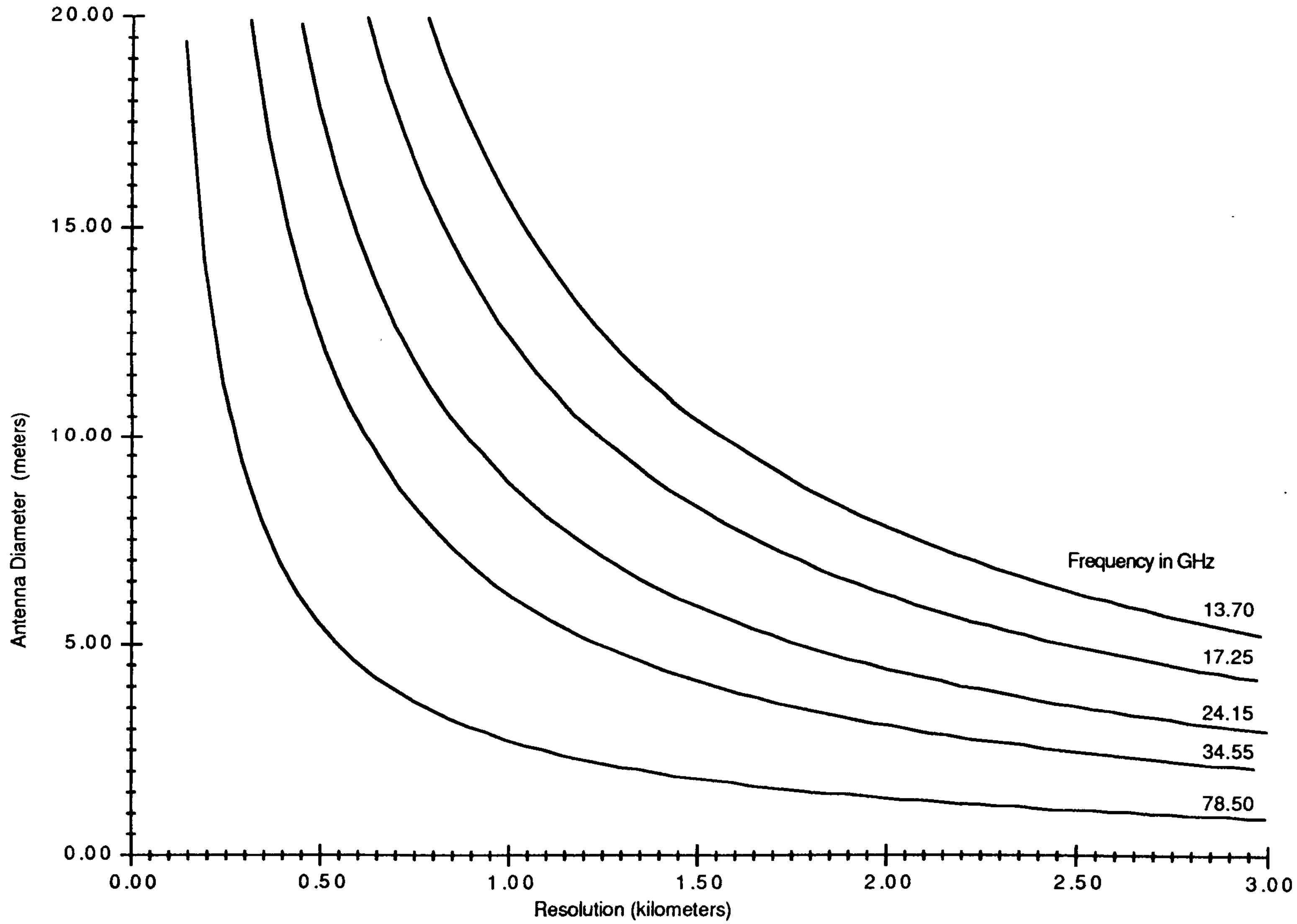
Utilizing equation (20) σ' becomes:

$$(26) \qquad \sigma' = p \sigma \left[\frac{\pi^3 R^2 \lambda^2 0.0389}{D^2 \cos \phi} \right]$$

The relationship between gain, resolution, and antenna diameter given by equations (7), (8), (11) and (18) were used to produce graphs 1 and 2. Graph 1 shows the required gain to achieve the desired resolution from various orbit altitudes. This reflects the required antenna size for a physically scanning system, i.e. not a synthetic aperture, and as can be seen from the graph, without the significantly increased processing gain of synthetic aperture techniques relatively high gain antennas will be required to perform SAR. Graph 2 shows the required antenna diameter *vs* resolution for some of the presently allocated active sensing bands. Table 1 below indicates the bands allocated below 100 GHz.



Graph 1. **Required Antenna Gain vs Resolution for Various Altitudes, 60 Degree Depression Angle**



Graph 2. **Required Antenna Diameter vs Resolution for Various Frequencies 60 Degree Depression Angle, 500 Kilometer Orbit Altitude**

Table 1. Allocations for Active Microwave Sensors

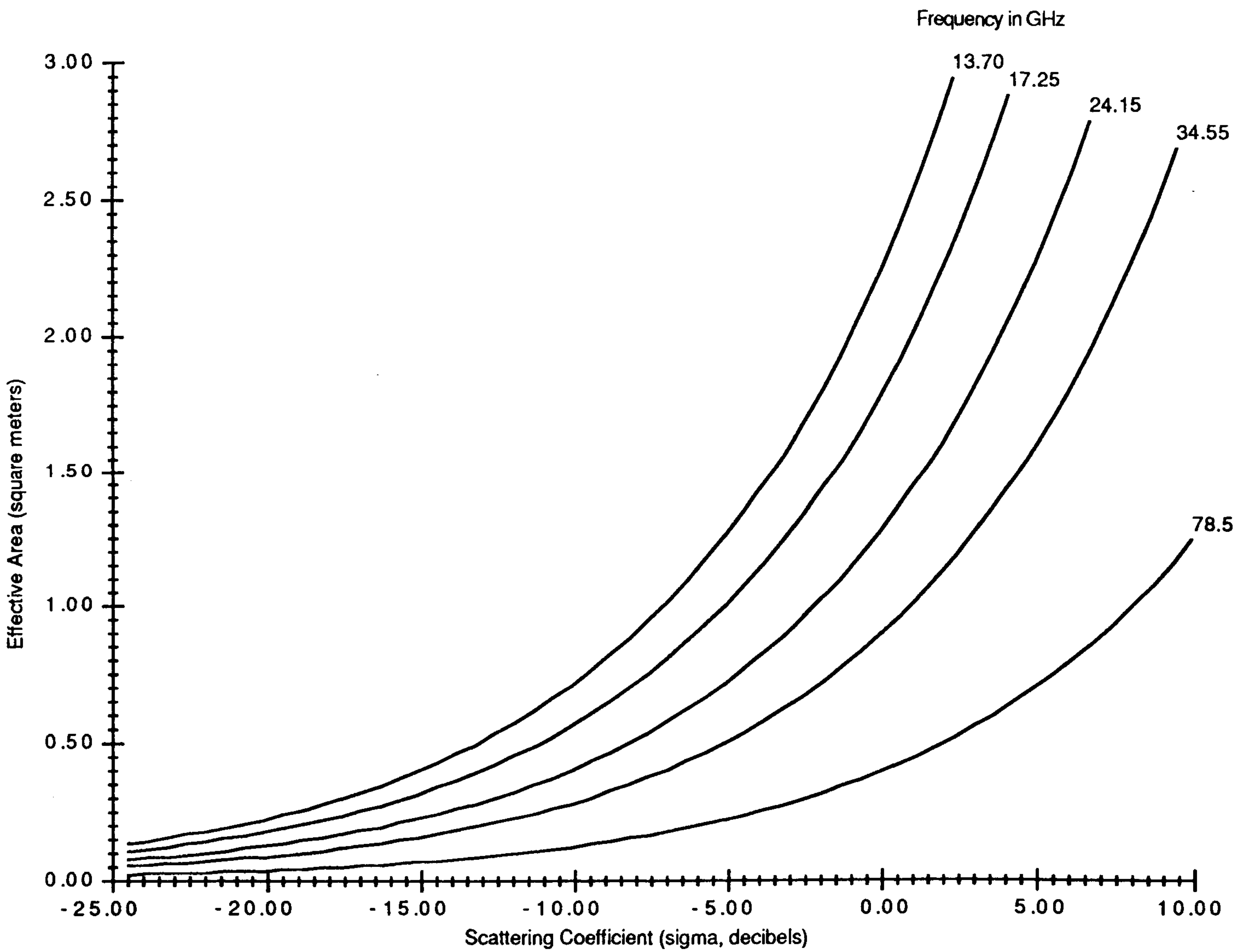
Frequency Band (GHz)	Wavelength (cm)
1.215 - 1.3	24.69 - 23.08
3.1 - 3.3	9.68 - 9.09
5.25 - 5.35	5.71 - 5.61
8.55 - 8.65	3.51 - 3.47
9.5 - 9.8	3.16 - 3.06
13.4 - 14.0	2.24 - 2.14
17.2 - 17.3	1.74 - 1.73
24.05 - 24.25	1.25 - 1.24
33.5 - 35.6	0.90 - 0.84
78. - 79.	0.38

Utilizing equations (3), (4), (16) and (26) graphs 3, 4, 5 and 6 were produced. Graph 3 shows the required passive reflector equivalent flat plate area to achieve an echo 15% above normal backscatter. This is plotted against the land scattering coefficient. Typical scattering coefficients will be between -30 and -5 dB for most land areas when sensing from 10 to 40 GHz. This was determined from data available in the "Manual of Remote Sensing", Vol 1., American Society of Photogrammetry, and Figure 3 of CCIR Report 850. As can be seen by graph 3 a relatively small (<1 meter^2) effective area is required to detect a 15% greater backscatter over most land areas when utilizing a 1 kilometer resolution. Graphs 4 and 5 show the edge dimension of a triangular and square trihedral reflector required to produce an echo at15% above normal backscatter. Graph 6 shows the required reflector effective area vs resolution. Appendix A contains similar graphs showing parametric relationships at single frequencies.

Discussion of Analysis

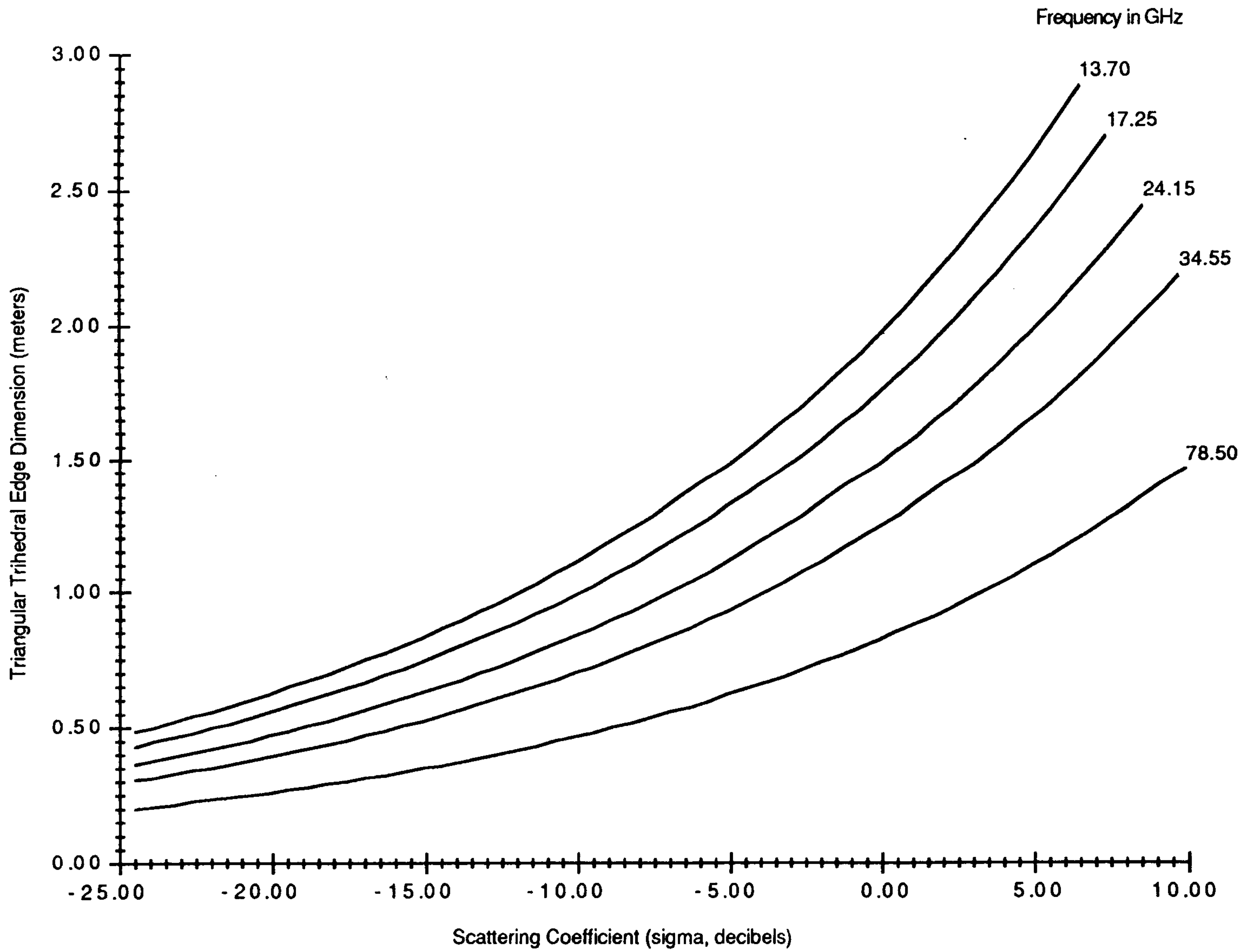
Certain general observations can be made from the calculations and graphs produced in this report. They are:

1. To be effective for search and rescue resolution must be kept to within a few kilometers. If the resolution was worse than a few kilometers it will be defeating its usefulness for locating distress sites. In addition a larger resolution will require a larger target in order to be detected; this is shown by graph 6.

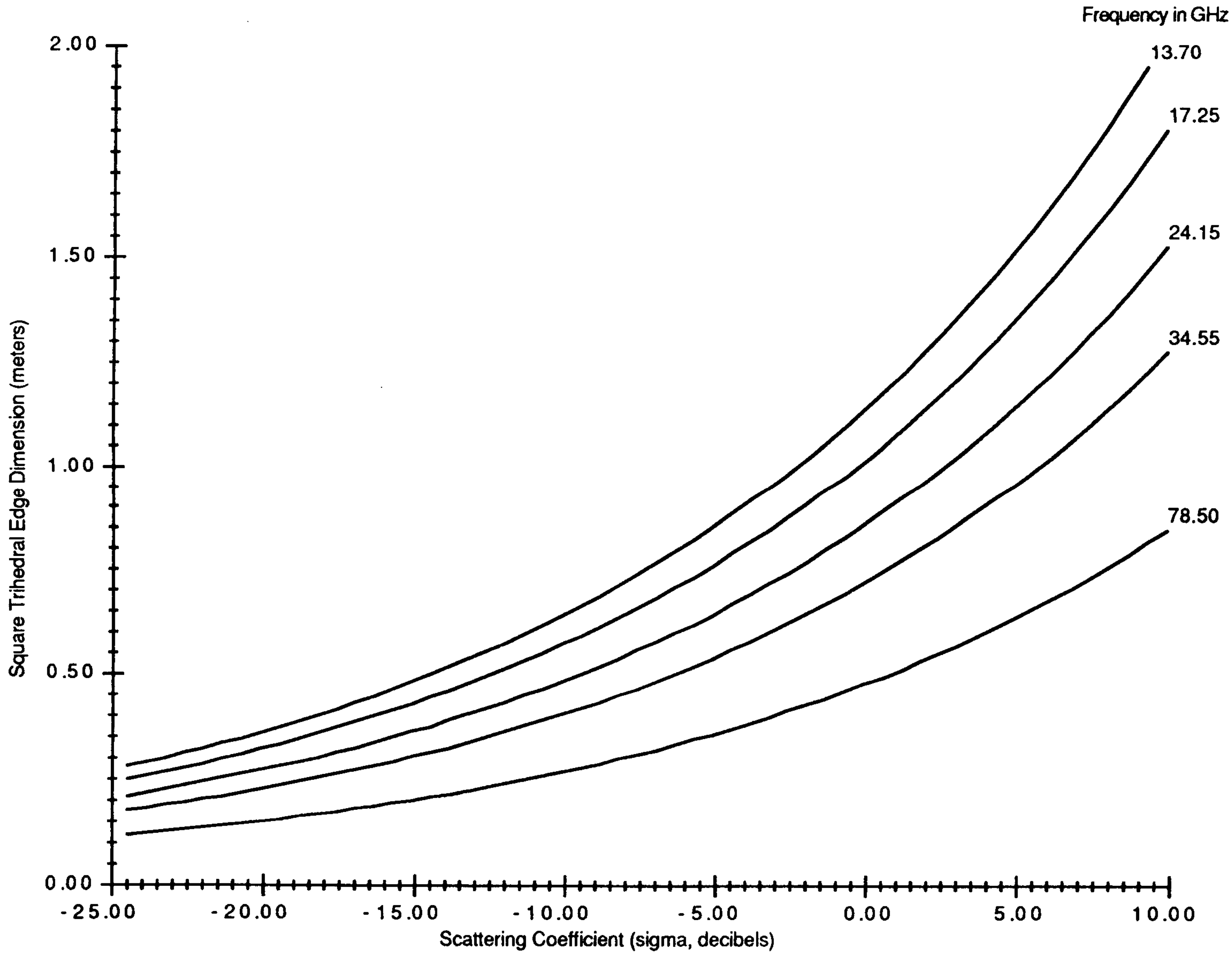


Graph 3. **Required Passive Reflector Effective Area vs Scattering Coefficient (sigma) for Various Frequencies**

Received Power 15% Above Normal Backscatter, 1 Kilometer Resolution, 60 Degree Depression Angle

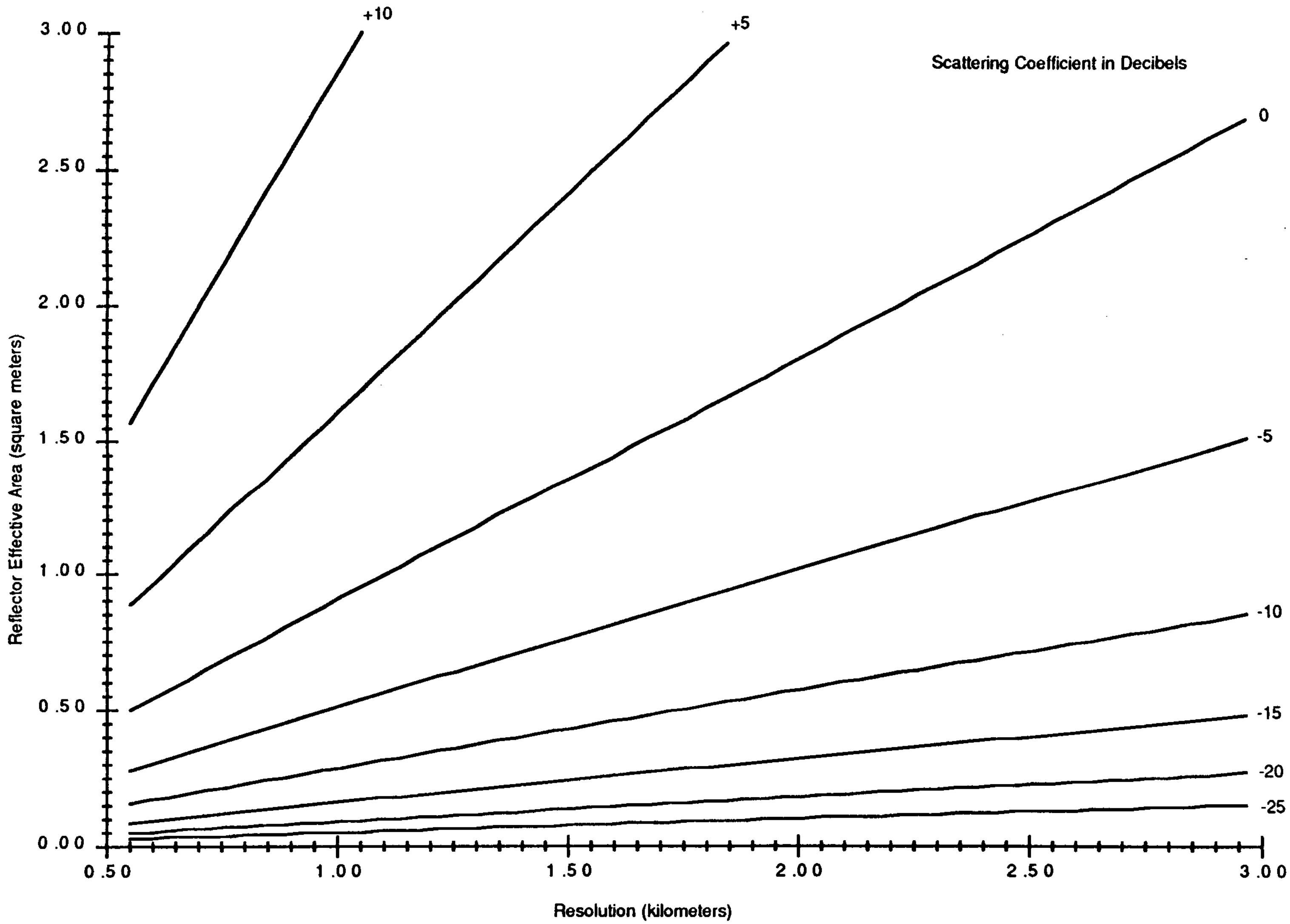


Graph 4. **Triangular Trihedral Edge Dimension vs Scattering Coefficient for Various Frequencies**
Received Power 15% Above Normal Backscatter, 1 Kilometer Resolution, 60 Degree Depression Angle



Graph 5. **Square Trihedral Edge Dimension vs Scattering Coefficient for Various Frequencies**

Received Power 15% Above Normal Backscatter, 1 Kilometer Resolution, 60 Degree Depression Angle



Graph 6. **Required Passive Reflector Effective Area vs Resolution for Various Scattering Coefficients**

34.55 GHz, 60 Degree Depression Angle, Power Received 15% Above Normal Background

2. Relatively high antenna gains are required to produce the desired resolutions when a scanning system, i.e. not synthetic aperture, is used to detect distress signals. This is apparent from graph 1 where it is shown that at least 54 dBi gain is required to produce a 2 km resolution from an orbit altitude of 300 km.

3. The antenna diameters necessary to produce the required gain, as shown in graph 2, may prohibit the use of a scanning system in the micowave region for SAR. The nature of the service and the high resolution that is required will necessitate the use of a low orbit sensor able to scan with a swath width many times greater than its resolution. The ability to rotate or scan with such a large antenna (greater than 3 meters in diameter) on a spacecraft is not presently feasible. There may, however be a way to utilize a modified parabola or circular reflector and a rotating antenna feed in a manner similar to the TDRS single access antennas to provide a scanning beam. Another alternative may be to use a zero momentum spacecraft where the large counter-rotating body of the spacecraft can be used to offset the momentum of the rotating antenna. The intent of this report is to address the possibility of using a simple scanning system, however another alternative is the use of synthetic aperture radar.

4. Irrespective of the sensor altitude, if a resolution less than 3 kilometers can be obtained the size of the reflector can be kept to a reasonable size, i.e. an effective area of less than 2 square meters, or trihedral reflectors with edge dimensions less than 2 meters. It has been shown in an experiment by NASA outlined in the publication "A Global Search and Rescue Concept Using Synthetic aperture Radar and Passive User Targets", NASA TN D-8172, that aluminized mylar can be supported by a light framework to produce a viable reflector target. Such a target can be be stowed in a compact form and set up in times of distress. This experiment was conducted using an aircraft flown at a 1.9 kilometer altitude utilizing synthetic aperture radar, and plans for a space shuttle test were being formulated.

5. Without the use of synthetic aperture radar resolution will be measured in kilometers. This will not allow the grouping of distress targets in known geometric patterns for better detection and identification of actual distress. This is a key issue in the synthetic aperture radar experiment. False indications of distress from a system that has a resolution on the order of kilometers may come from almost any metallic object such as ships, drilling platforms, airplanes at sea, or cars, trucks, buildings, or towers on land. Such a preponderance of false indications would render the system worthless.

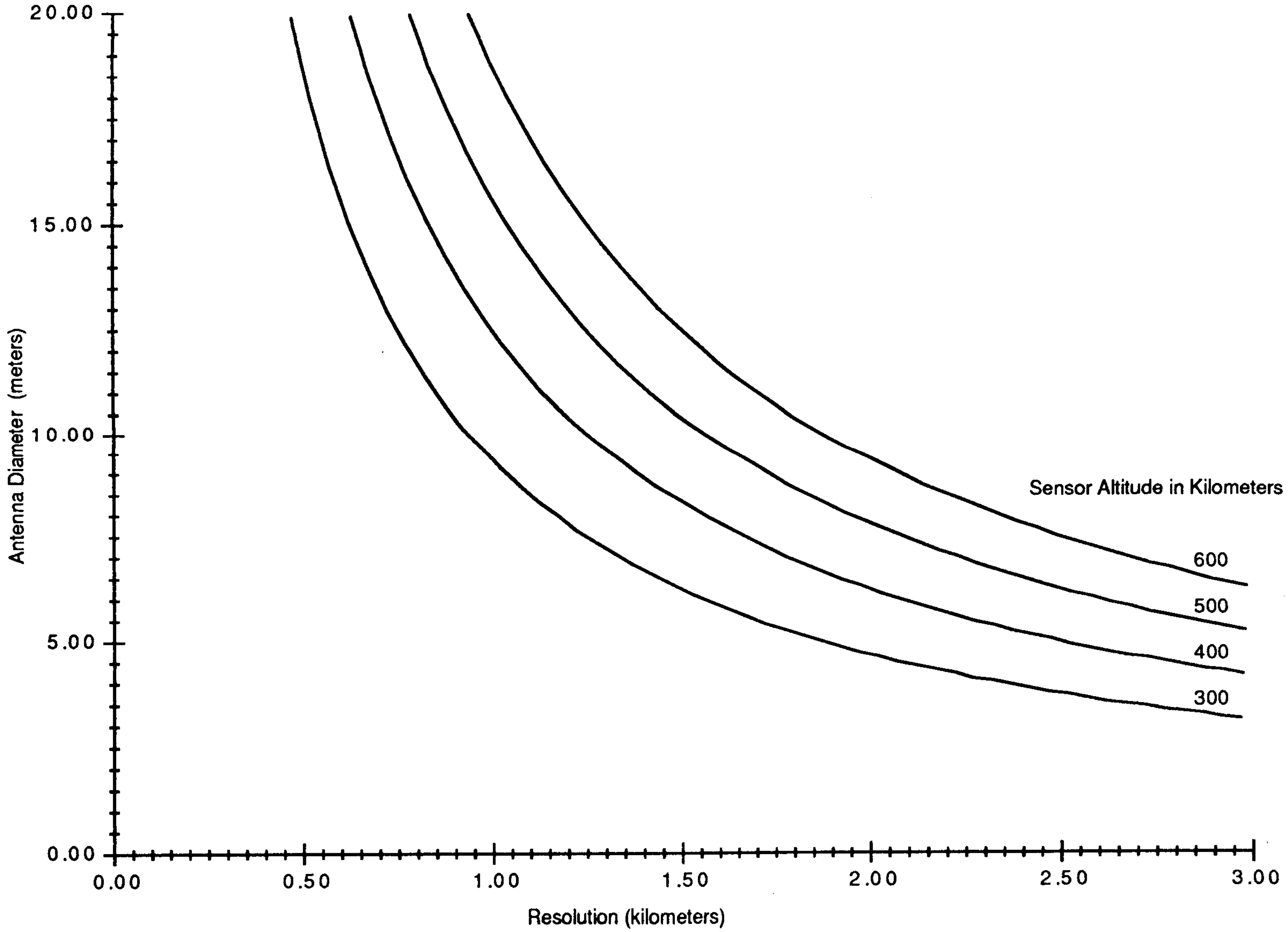
6. A low orbiting system providing resolution in the kilometer range may prove useful for narrowing the search area for terrestrial SAR craft. Instead of searching wide areas of ocean or land, searches can be confined to within an area the size of the sensor resolution. Radar on terrestrial SAR craft can then be used within these areas to pin-point distress sites.

Conclusions

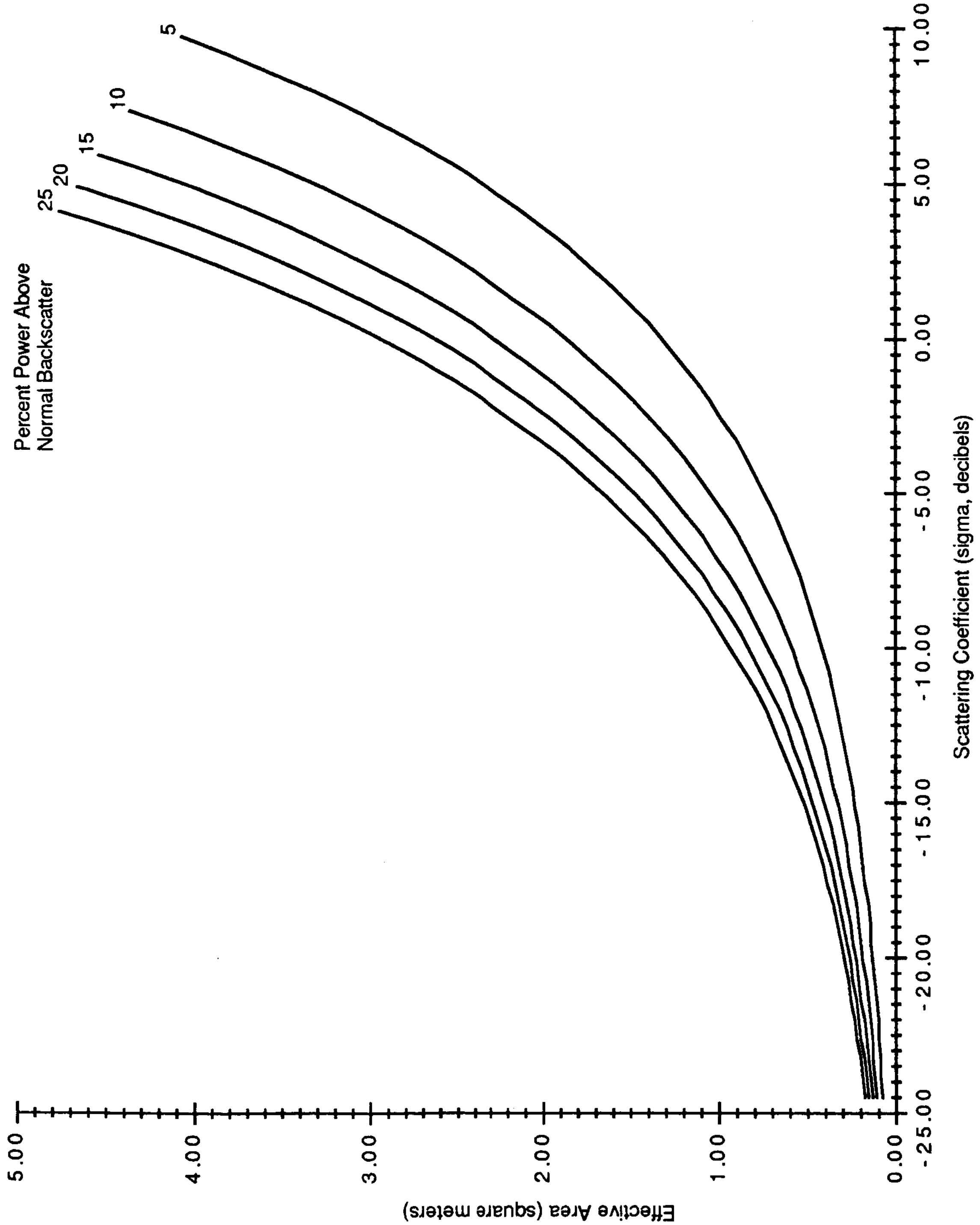
At least three points can be identified which will require significant efforts to produce a viable search and rescue system. One, sufficient antenna gain will be required to achieve adequate resolution on the order of one to three kilometers. Two, a means of scanning will have to be devised, whether by rotating the entire antenna or only the antenna feed. And three, a means of positively identifying distress signals from false echos will have to be devised. Distress signals will most likely come from remote areas on land or at sea. Objects producing high reflectivity will probably be manmade and will for the most part be located near populated areas, areas where a global SAR system will not be required. Therefore, prior knowledge of an area being sensed, and an indication of potential distress, i.e. overdue communications, distress calls, etc., will aid in reducing false distress signals and speed location detection. Aid in locating a known distress situation may be sufficient to warrant development of such a system, however, some new procedure or technique will still have to be developed in order to produce a system that can provide the initial detection of distress.

Appendix A

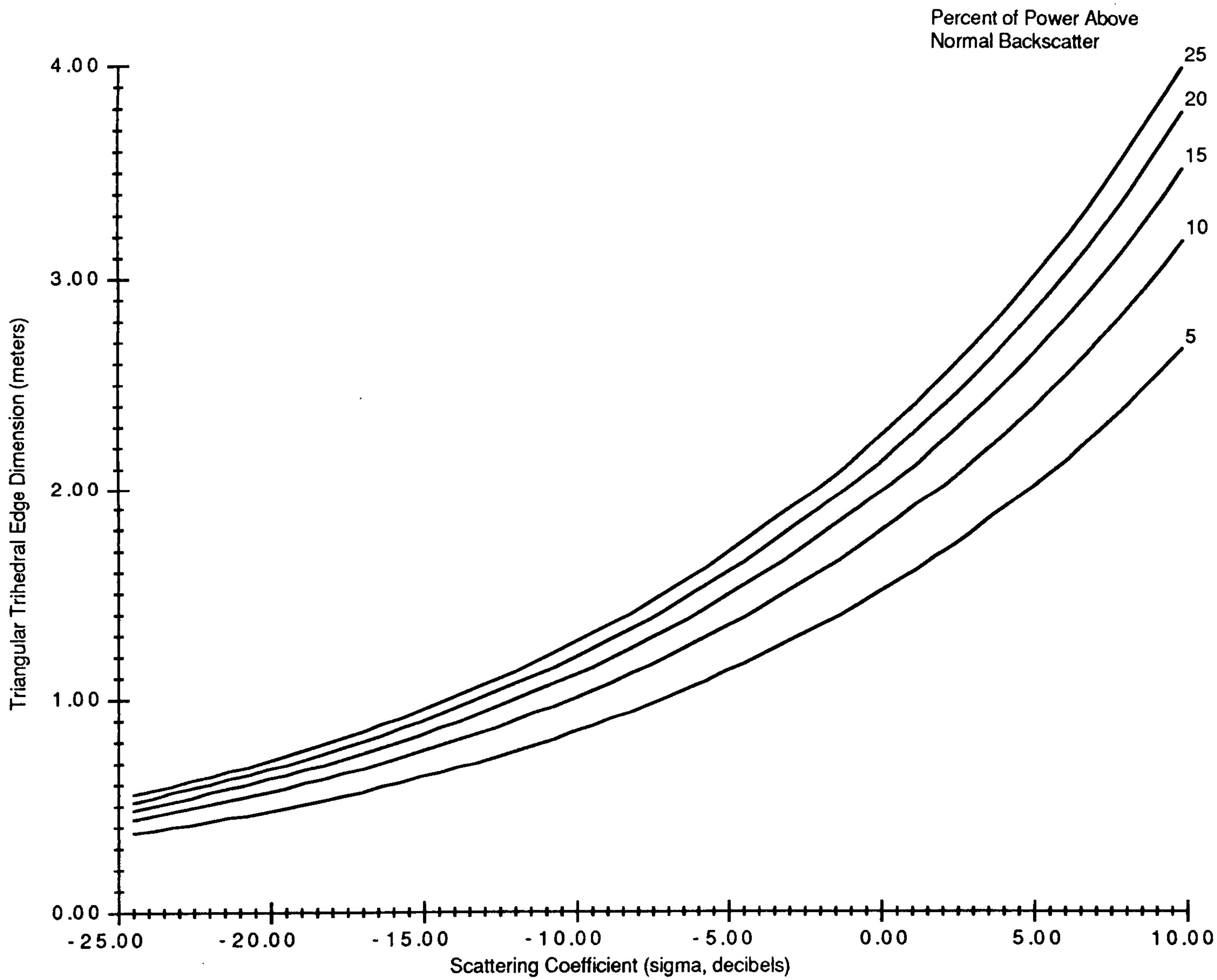
Parametric Relationships at Specific Sensing Frequencies
Between Antenna Diameter and Resolution
and Between Passive Reflectors and Scattering Coefficients



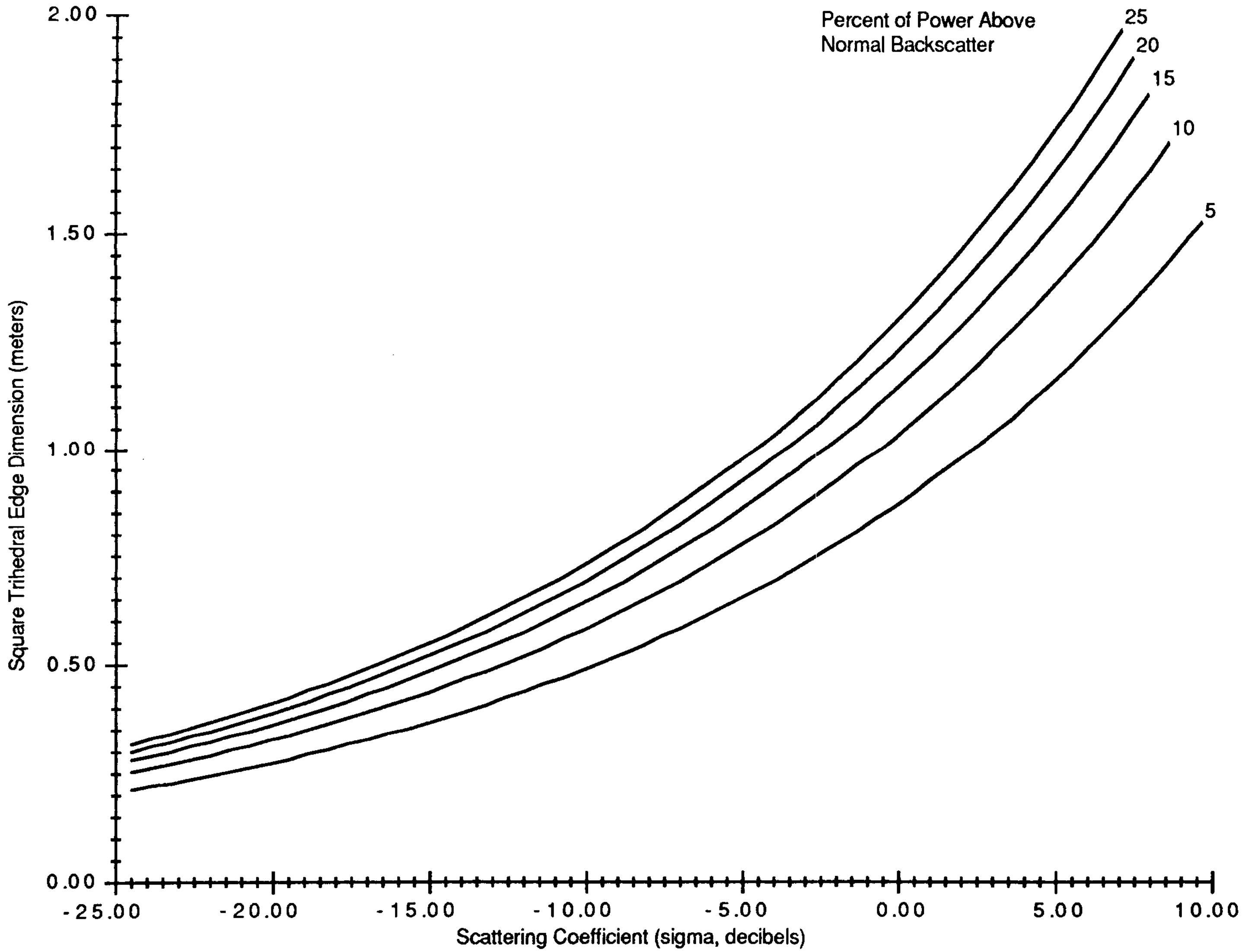
Required Antenna Diameter vs Resolution for Various Altitudes
60 Degree Depression Angle, 13.7 GHz



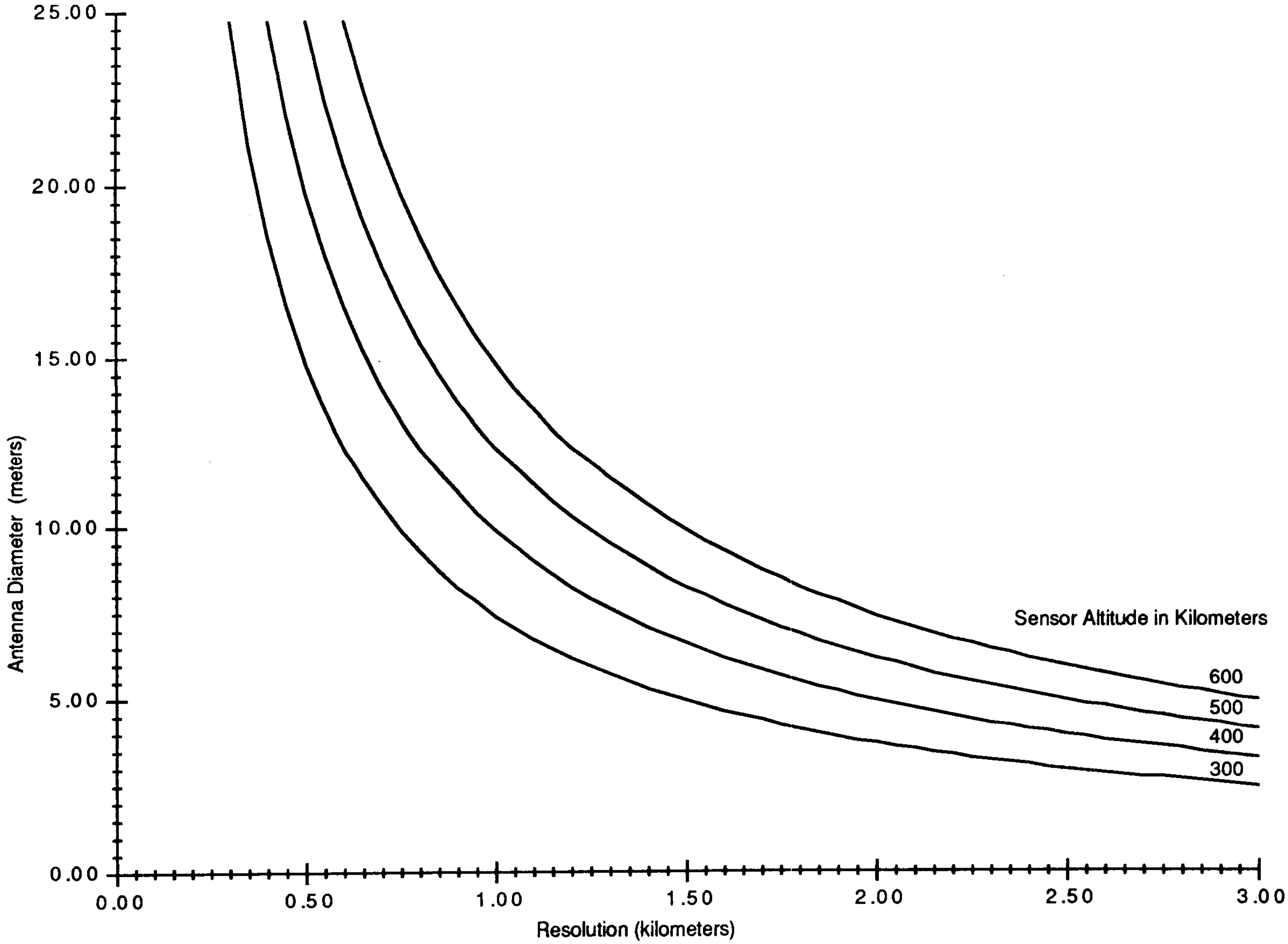
Required Passive Reflector Effective Area vs Scattering Coefficient (sigma) for Percent Power Above Normal Backscatter, 1 km Resolution at 13.7 GHz



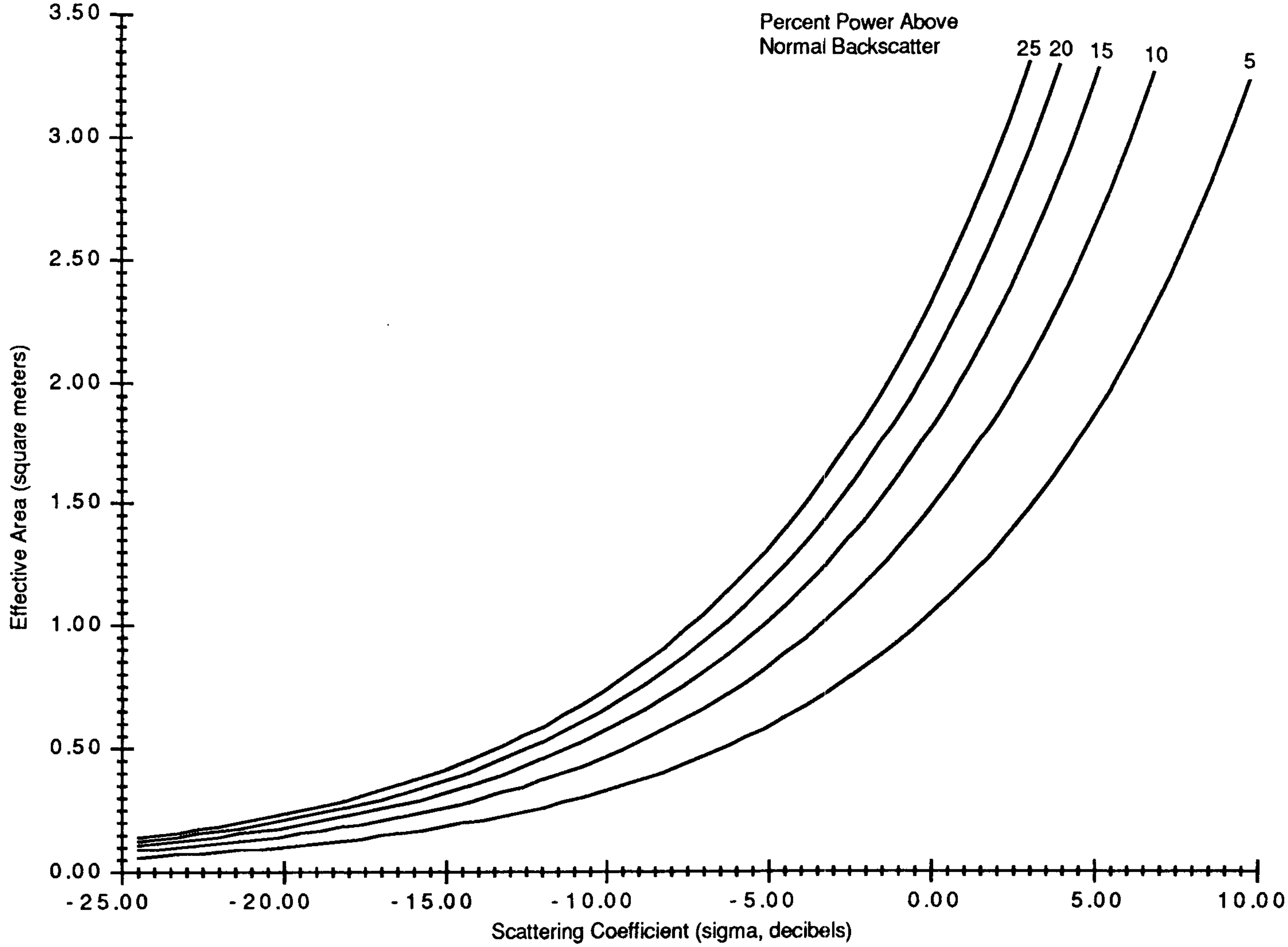
Triangular Trihedral Edge Dimension vs Scattering Coefficient for Percent Power Above Normal Backscatter, 1 km Resolution, 13.7 GHz



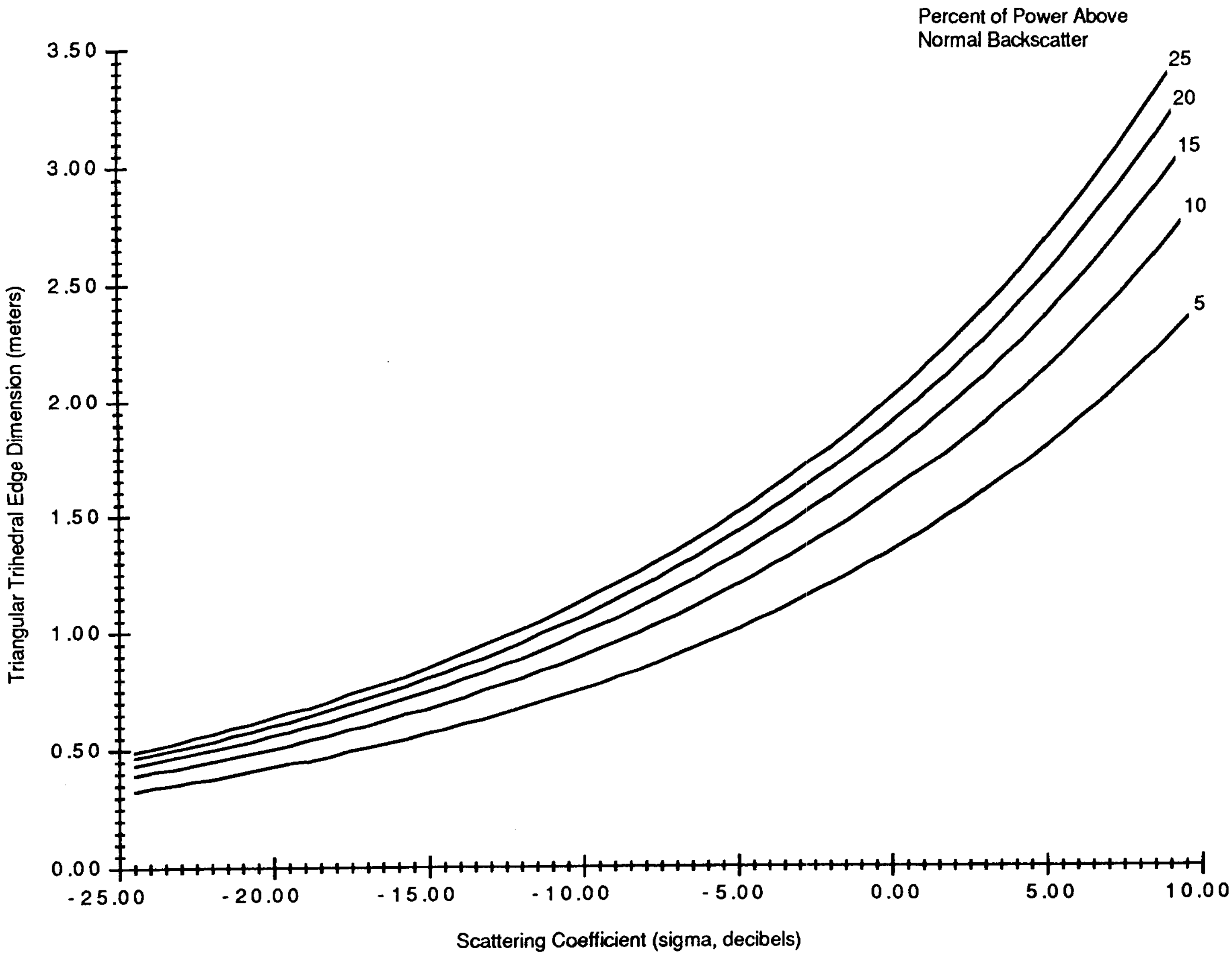
Square Trihedral Edge Dimension vs Scattering Coefficient for Percent Power Above Normal Backscatter, 1 km Resolution, 13.7 GHz



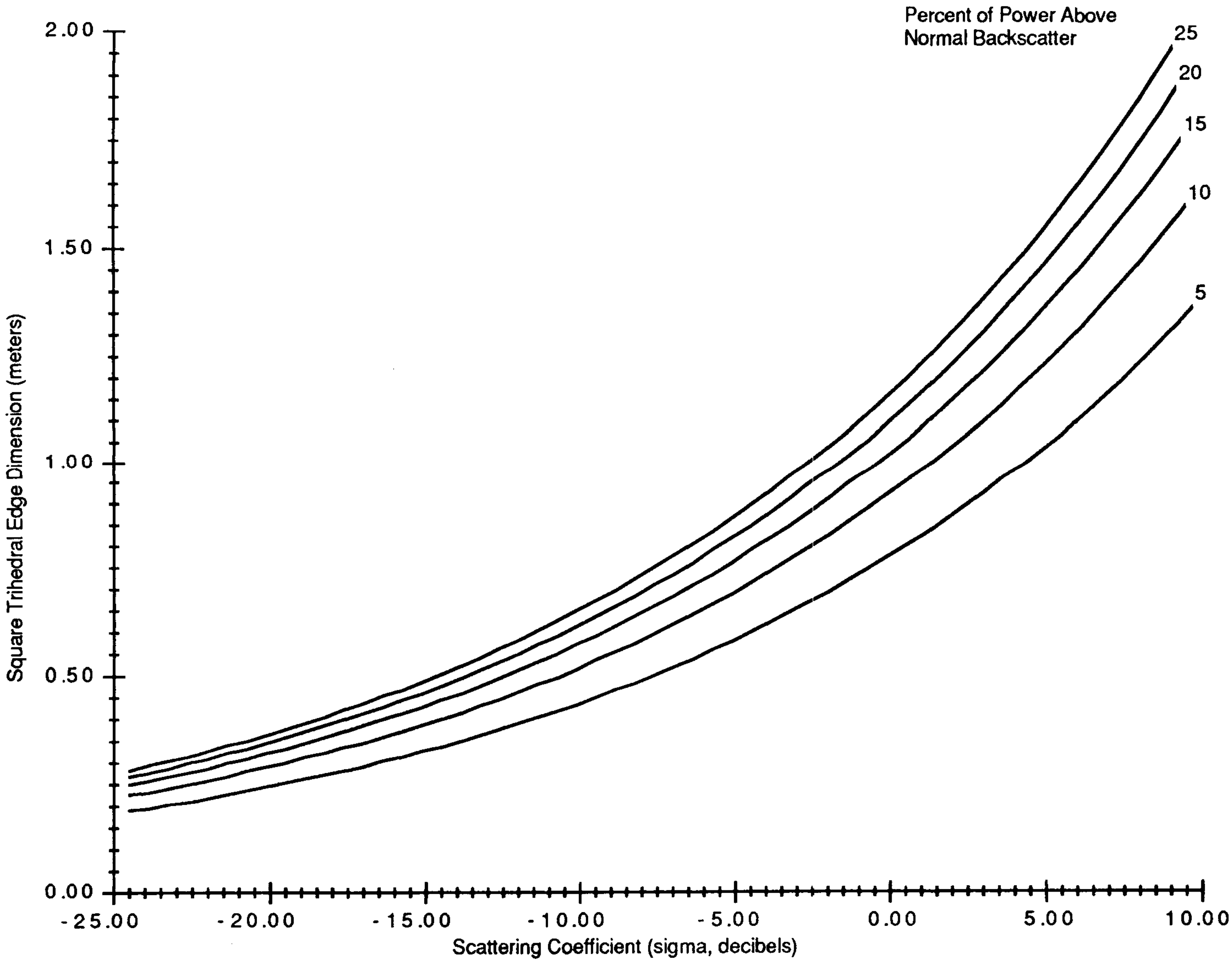
Required Antenna Diameter vs Resolution for Various Altitudes
60 Degree Depression Angle, 17.25 GHz



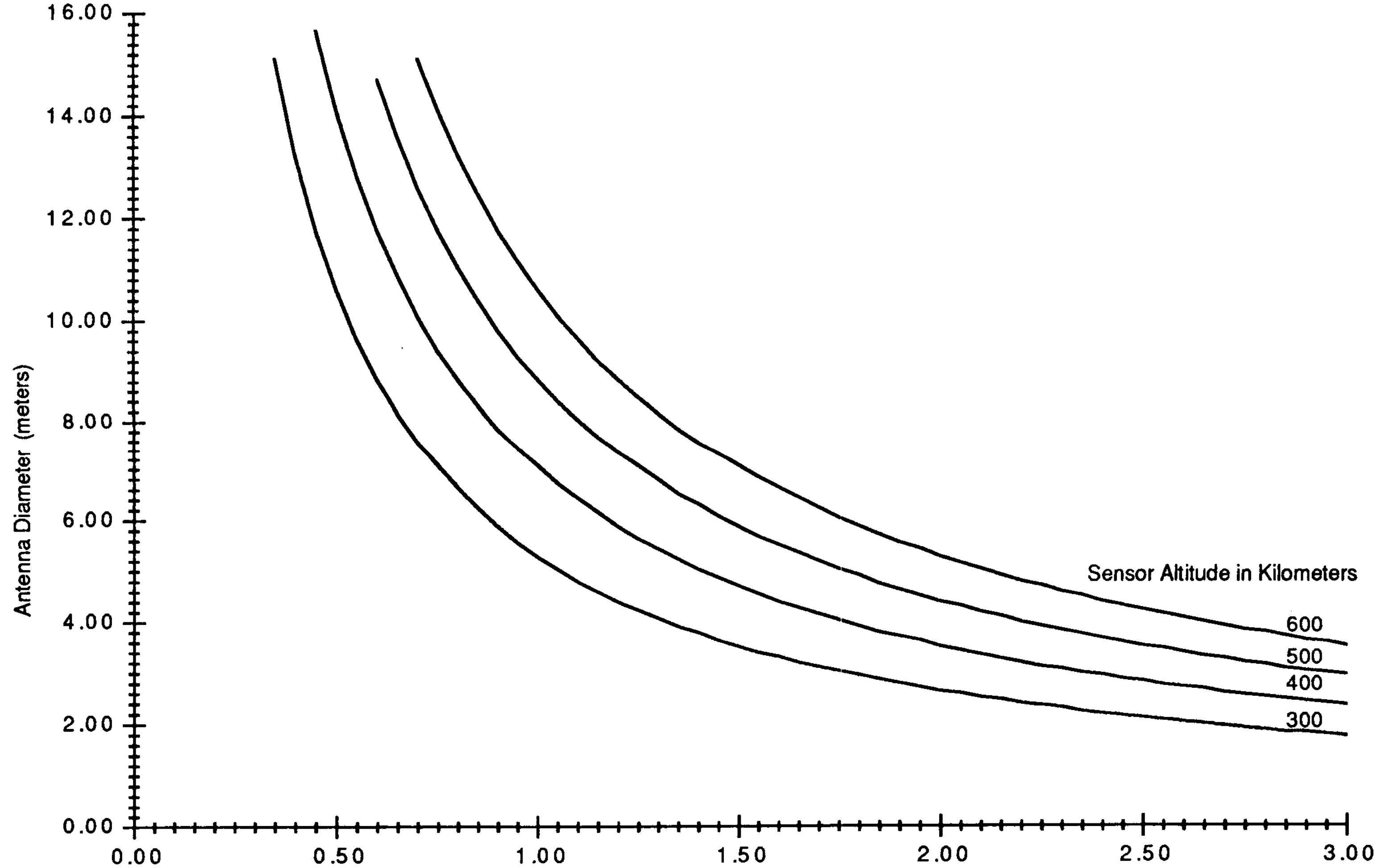
Required Passive Reflector Effective Area vs Scattering Coefficient (sigma) for Percent Power Above Normal Backscatter, 1 km Resolution at 17.25 GHz



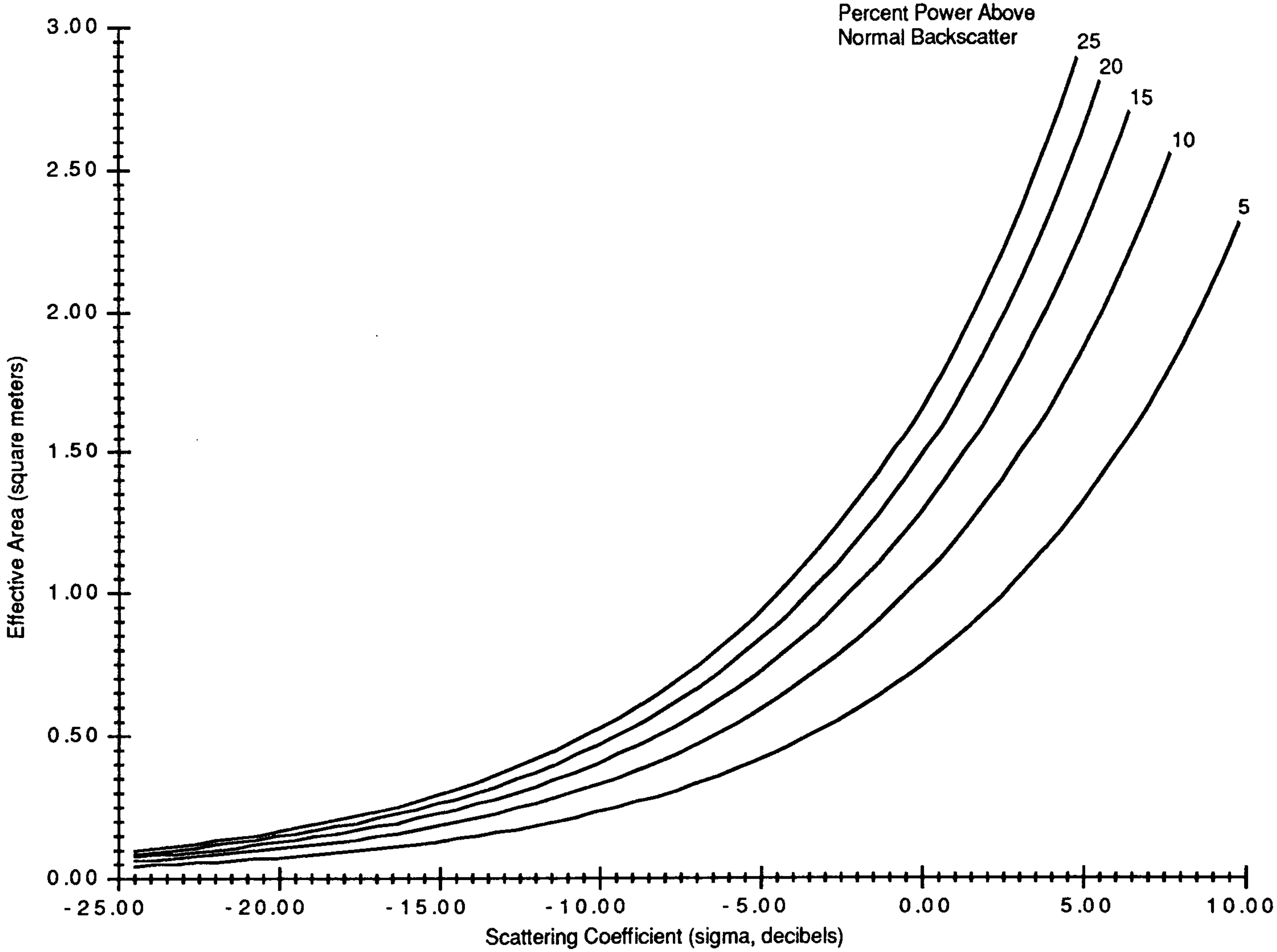
Triangular Trihedral Edge Dimension vs Scattering Coefficient for Percent Power Above Normal Backscatter, 1 km Resolution, 17.25 GHz



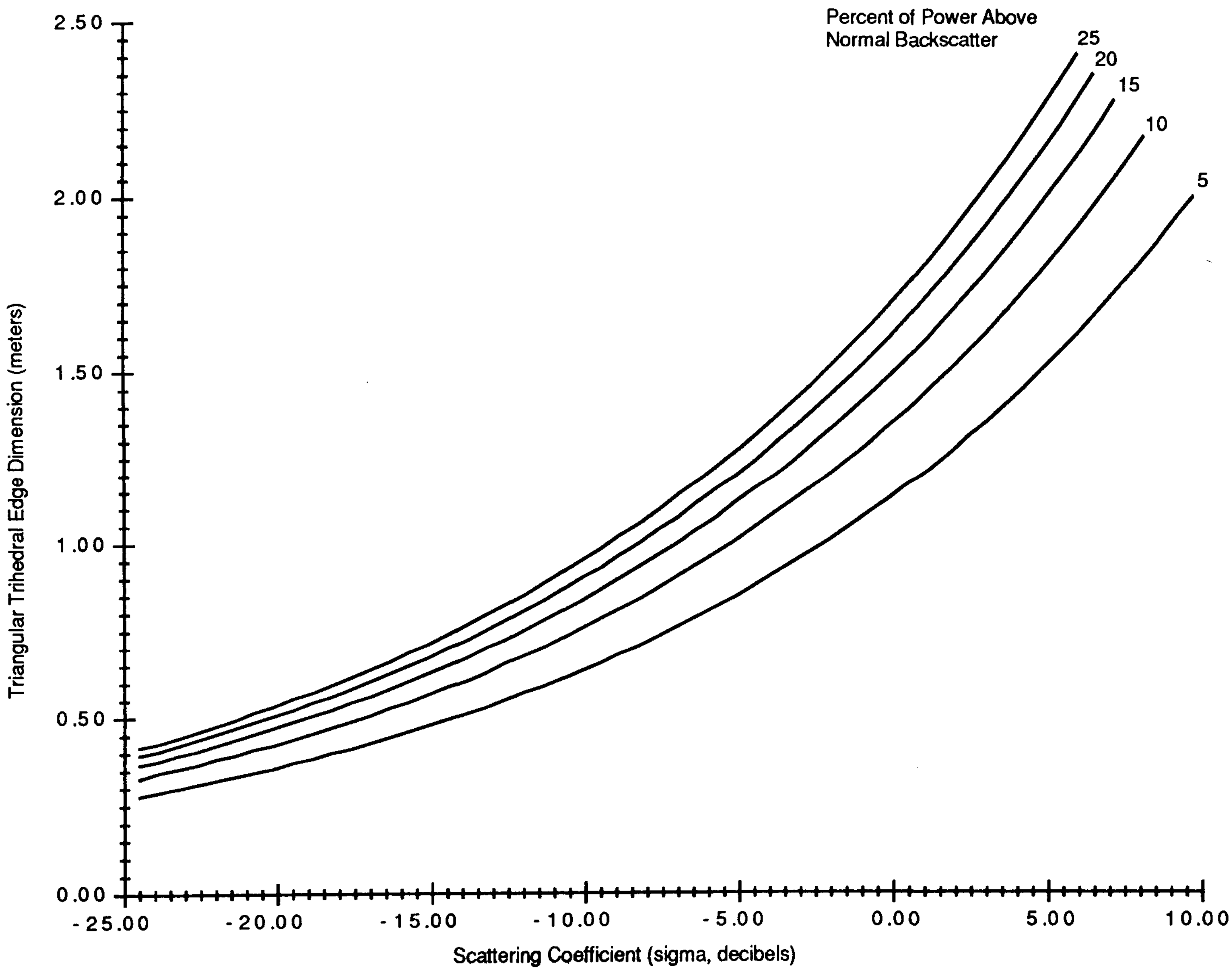
Square Trihedral Edge Dimension vs Scattering Coefficient for Percent Power Above Normal Backscatter, 1 km Resolution, 17.25 GHz



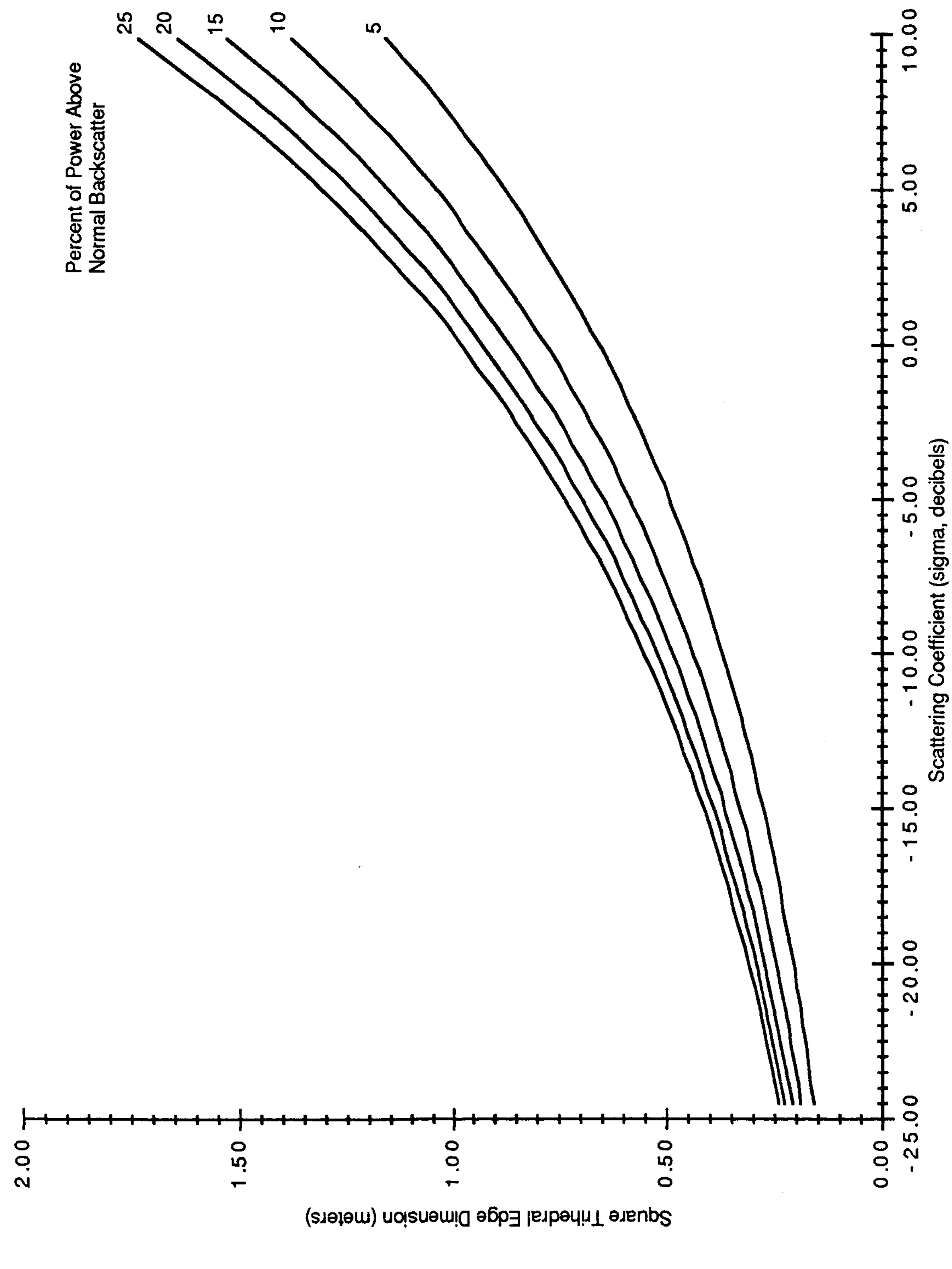
Required Antenna Diameter vs Resolution for Various Altitudes
60 Degree Depression Angle, 24.15 GHz



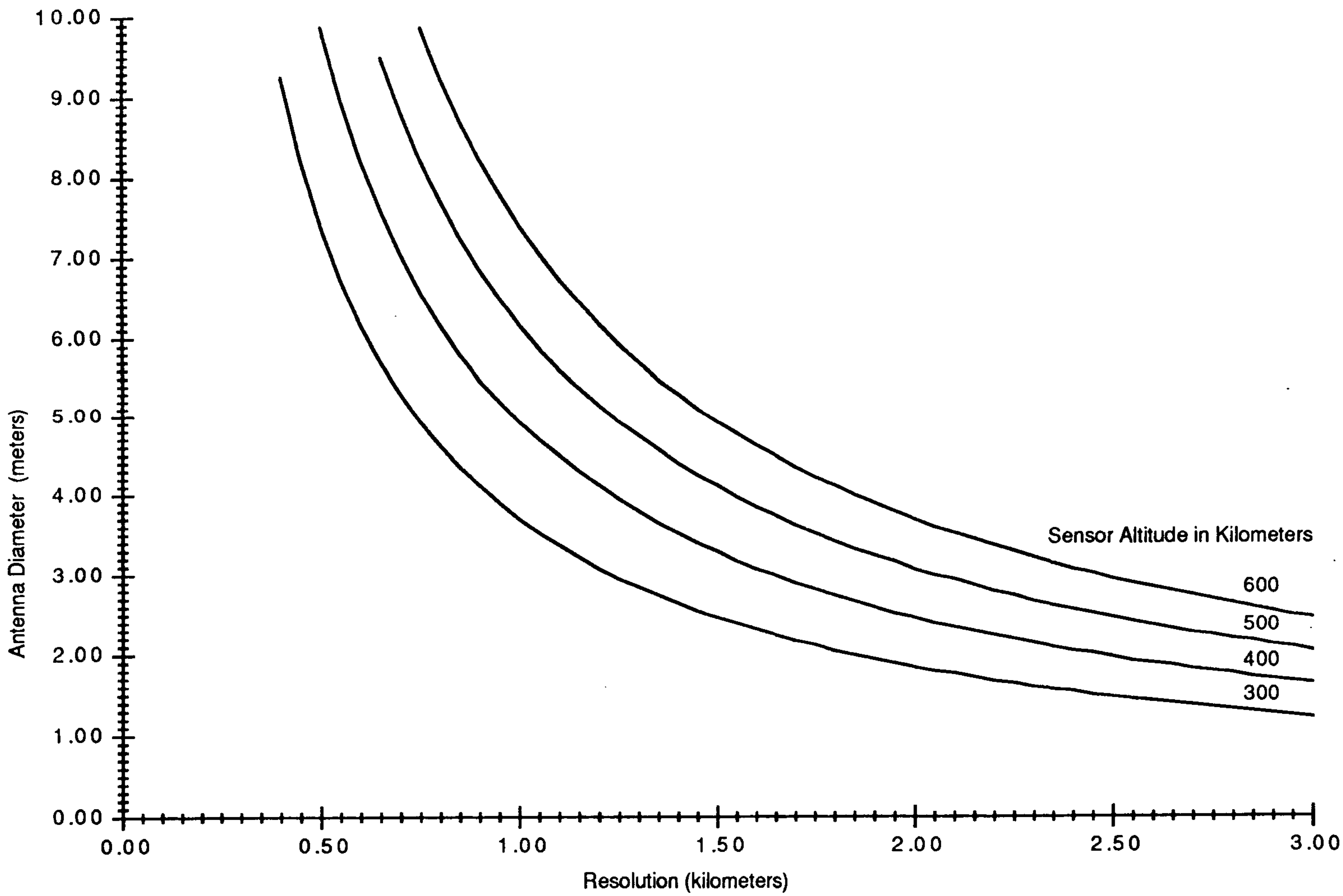
Required Passive Reflector Effective Area vs Scattering Coefficient (sigma) for Percent Power Above Normal Backscatter, 1 km Resolution at 24.15 GHz



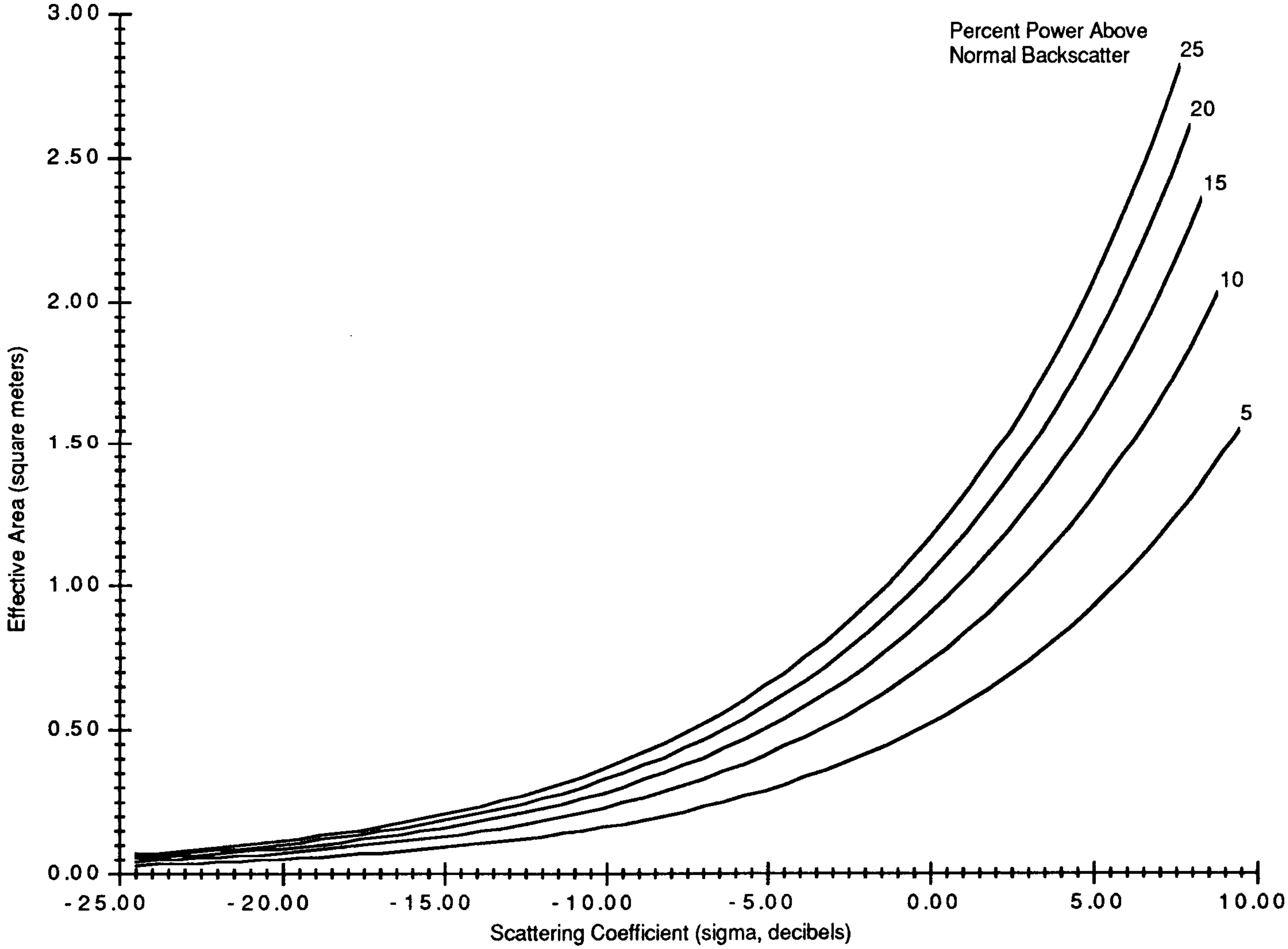
Triangular Trihedral Edge Dimension vs Scattering Coefficient for Percent Power Above Normal Backscatter, 1 km Resolution, 24.15 GHz



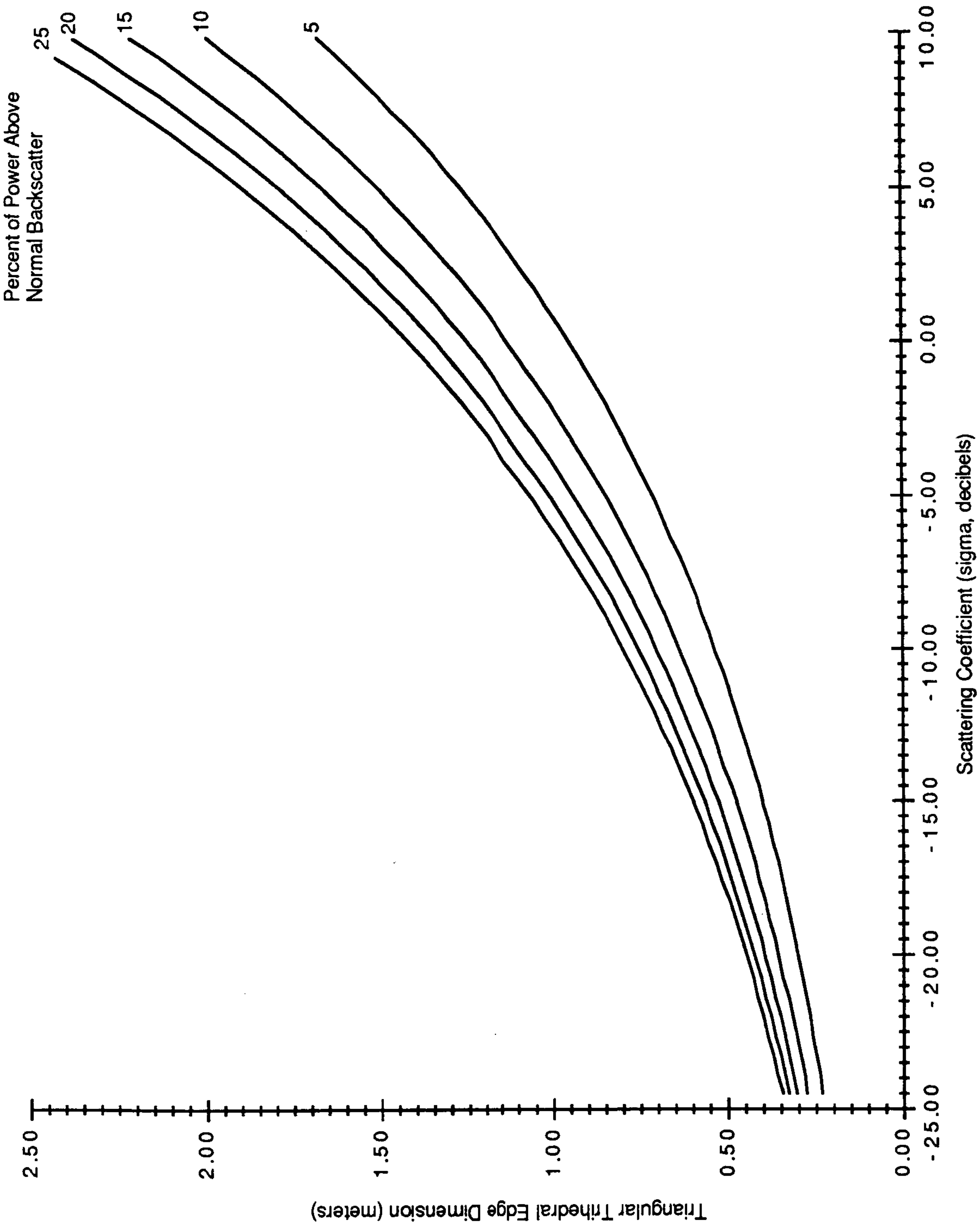
Square Trihedral Edge Dimension vs Scattering Coefficient for Percent Power Above Normal Backscatter, 1 km Resolution, 24.15 GHz



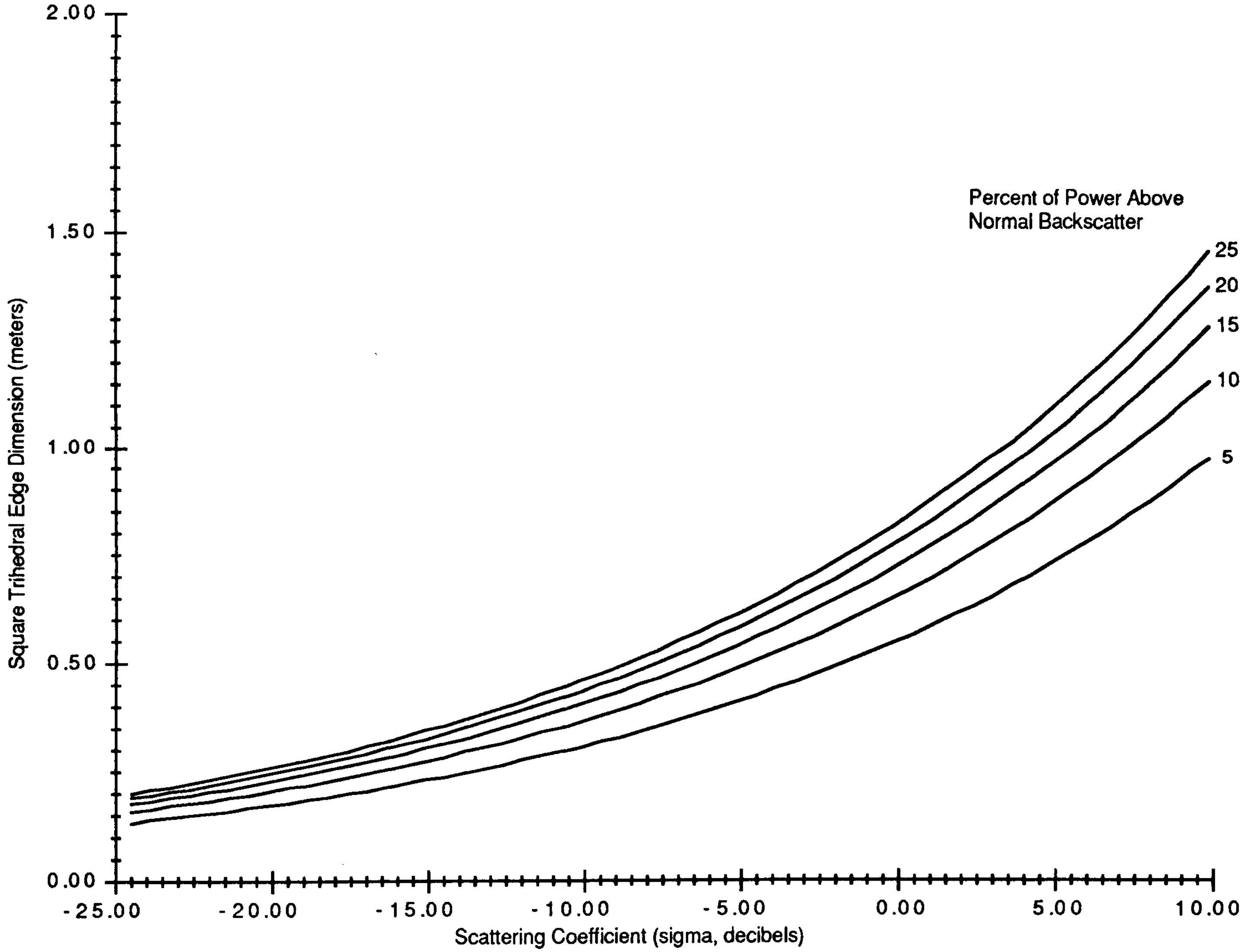
Required Antenna Diameter vs Resolution for Various Altitudes
60 Degree Depression Angle, 34.55 GHz



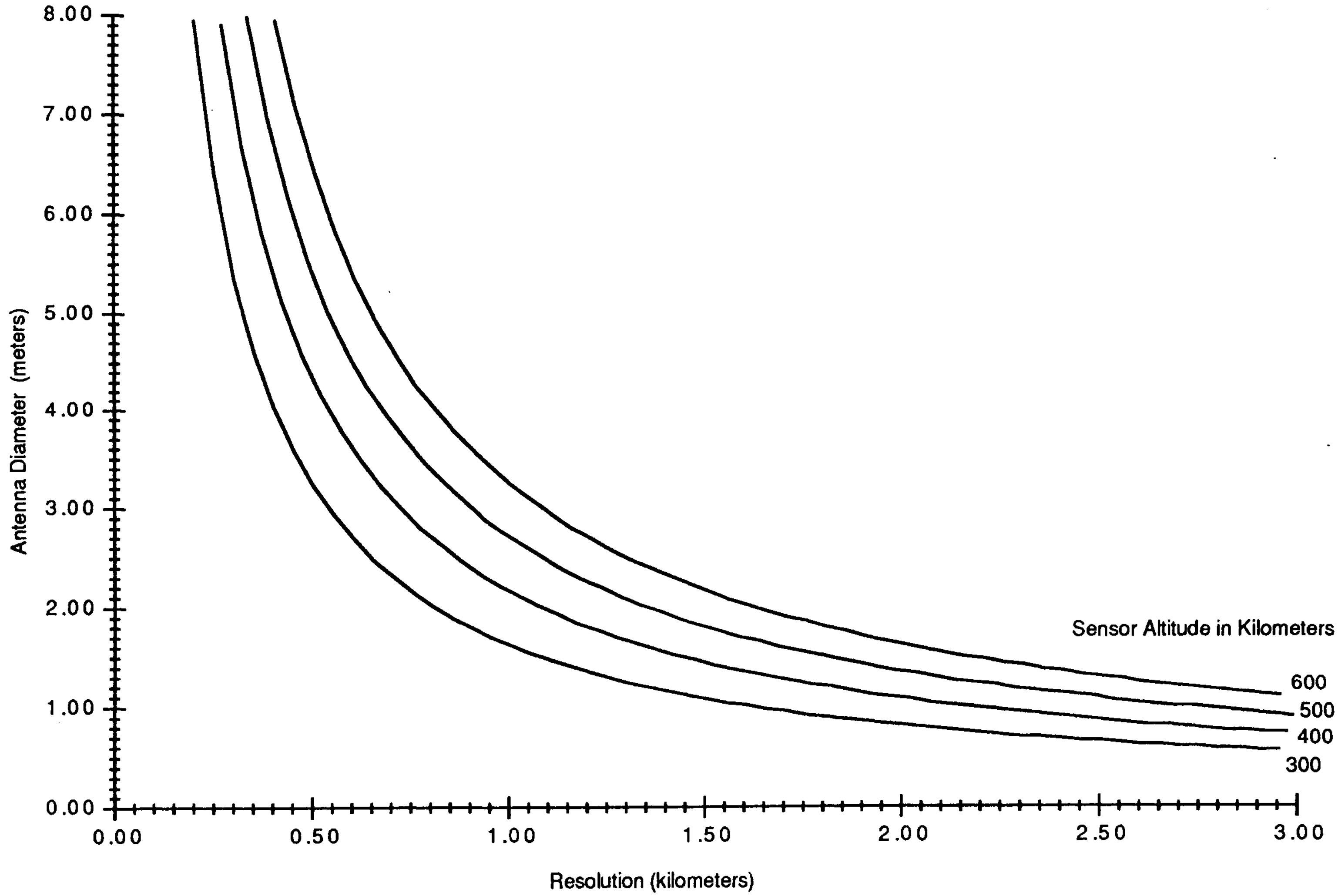
Required Passive Reflector Effective Area vs Scattering Coefficient (sigma) for Percent Power Above Normal Backscatter, 1 km Resolution at 34.55 GHz



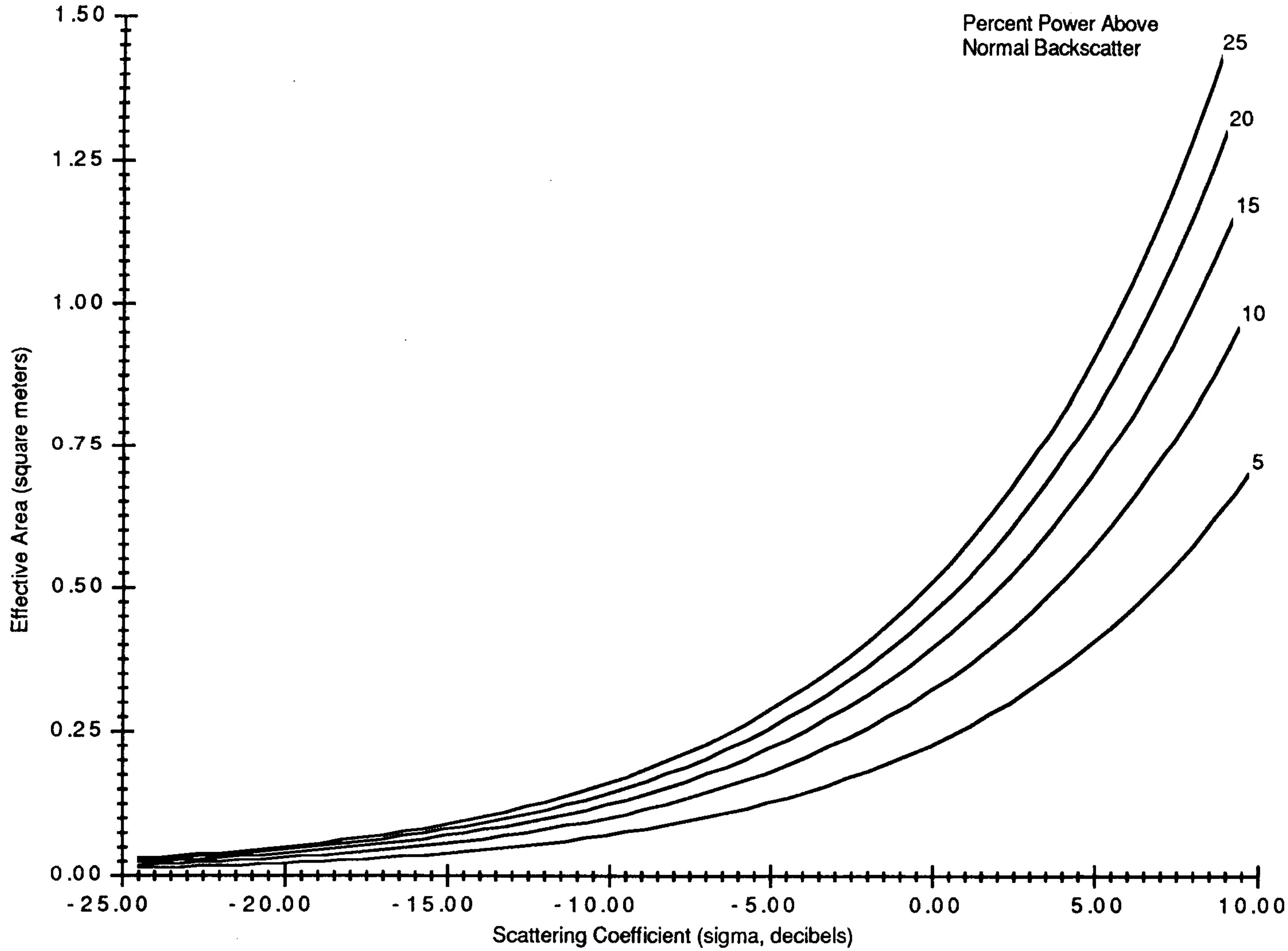
Triangular Trihedral Edge Dimension vs Scattering Coefficient for Percent Power Above Normal Backscatter, 1 km Resolution, 34.55 GHz



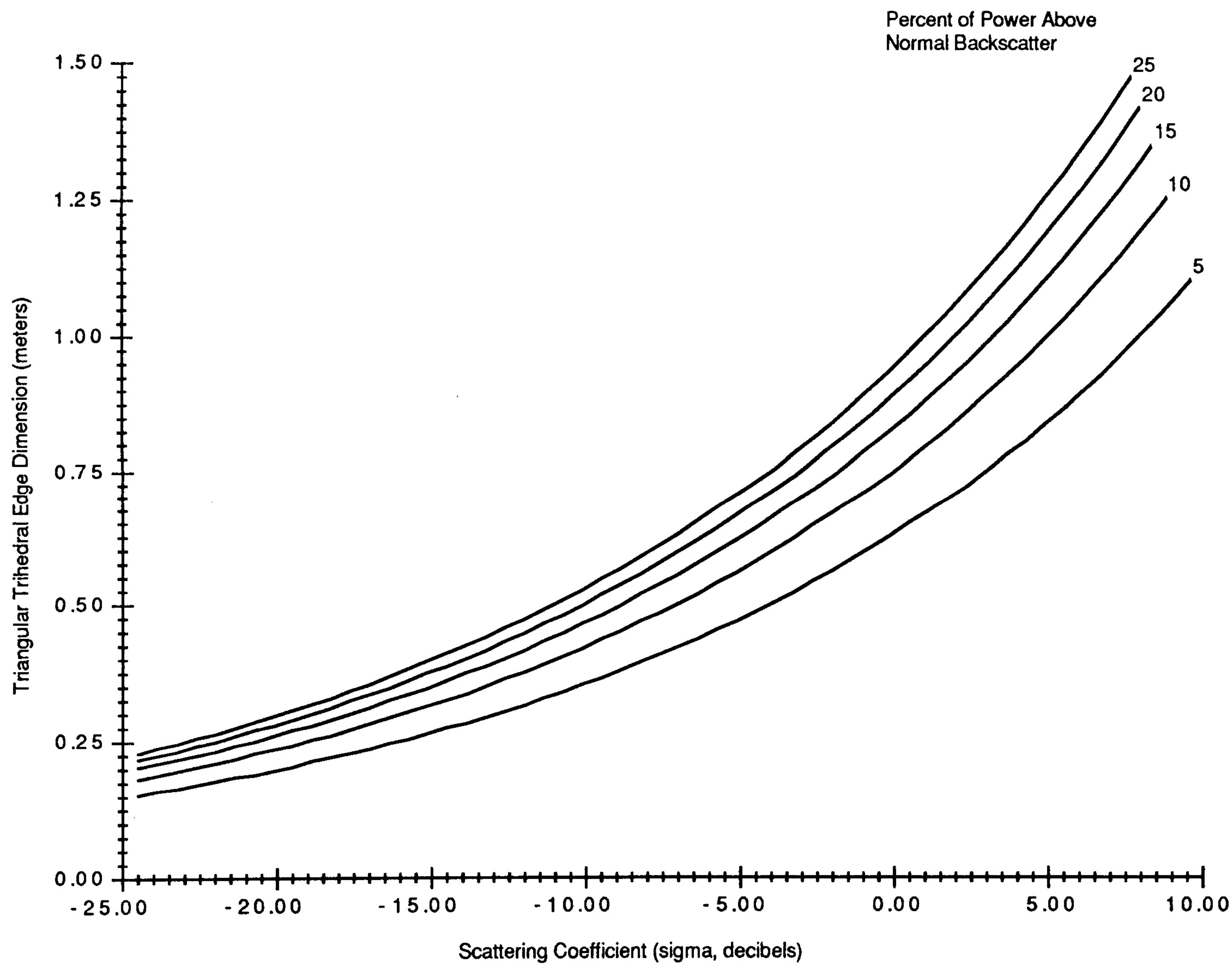
Square Trihedral Edge Dimension vs Scattering Coefficient for Percent Power Above Normal Backscatter, 1 km Resolution, 34.55 GHz



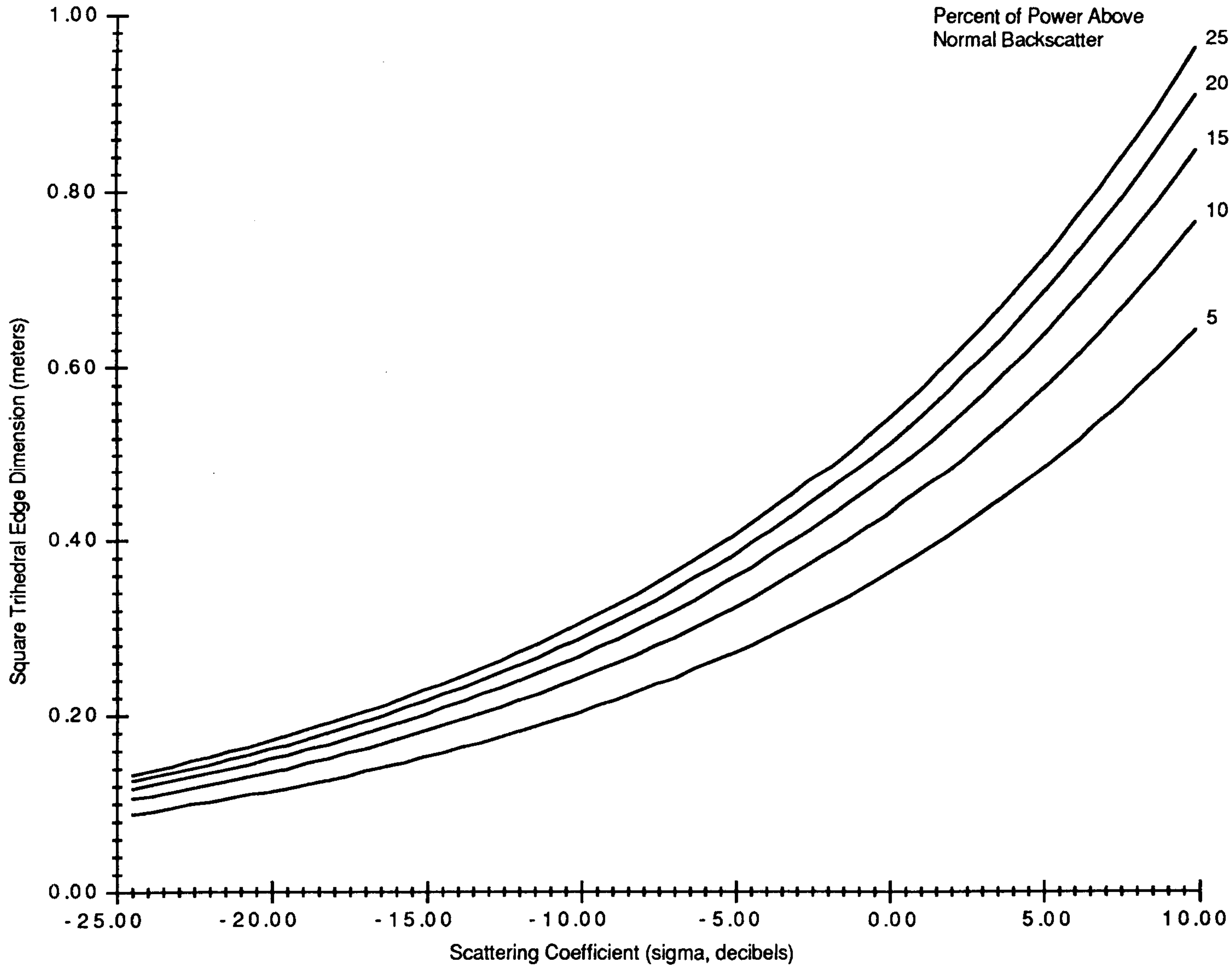
**Required Antenna Diameter vs Resolution for Various Altitudes
60 Degree Depression Angle, 78.5 GHz**



Required Passive Reflector Effective Area vs Scattering Coefficient (sigma) for Percent Power Above Normal Backscatter, 1 km Resolution at 78.5 GHz



Triangular Trihedral Edge Dimension vs Scattering Coefficient for Percent Power Above Normal Backscatter, 1 km Resolution, 78.5 GHz



Square Trihedral Edge Dimension vs Scattering Coefficient for Percent Power Above Normal Backscatter, 1 km Resolution, 78.5 GHz