

RECOMMENDATION ITU-R RS.1449*

**FEASIBILITY OF SHARING BETWEEN THE FSS (SPACE-TO-EARTH) AND THE EARTH
EXPLORATION-SATELLITE (PASSIVE) AND SPACE RESEARCH (PASSIVE)
SERVICES IN THE BAND 18.6-18.8 GHz**

(Question ITU-R 215/7)

(2000)

The ITU Radiocommunication Assembly,

considering

- a) that the 18.6-18.8 GHz band is allocated to the FSS (space-to-Earth) on a primary basis;
- b) that the 18.6-18.8 GHz band is allocated to the Earth exploration-satellite service (EESS) (passive) and space research service (SRS) (passive) on a primary basis in Region 2 and on a secondary basis in Regions 1 and 3;
- c) that RR No. S5.523 states that administrations are requested to limit as far as practicable the pfd at the Earth's surface in the band 18.6-18.8 GHz, in order to reduce the risk of interference to passive sensors in the EESS and space research service;
- d) that passive sensing in this band is necessary to obtain critical environmental measurements on a worldwide basis and no other frequency band is available that could replace this band;
- e) that the band 18.6-18.8 GHz is very important for use by FSS in view of the large number of systems in the planning stage and of the presence of some systems already in operation;
- f) that studies have been conducted assessing the aggregate interference into a passive spaceborne sensor from multiple FSS transmitting satellites, all utilizing spot beams and having a common service area, and have found that constraints are needed on both FSS and EESS (passive) systems if sharing is to take place (see Annex 1);
- g) that studies have shown that FSS satellites in 8, 12 and 24 h highly elliptical orbits (HEO) cause less interference to the sensor than GSO FSS satellites (see Annex 2),

recommends

- 1 that passive sensors operating in the EESS and SRS and acquiring data over land masses be designed to collect data only when travelling north in the northern hemisphere and south in the southern hemisphere and utilize an antenna that is inclined about 40° from nadir and scans in azimuth about the velocity vector of the spacecraft;
- 2 that passive sensors be designed to operate in an interference environment based on a pfd produced by a FSS at the surface of the Earth limited to -95 dB(W/m²) across the 18.6-18.8 GHz band; this value could be exceeded by up to 3 dB for no more than 5% of the time.

ANNEX 1

**An evaluation of potential interference into the EESS (passive) in the
18.6-18.8 GHz band from GSO satellites operating in the FSS**

1 Introduction

Spaceborne microwave science sensors make use of very narrow beam antennas to obtain such information as surface temperature, moisture content, sea state and others. Certain passive sensors make use of the 18.6-18.8 GHz band. This same band is shared with GSO satellite systems operating in the FSS. There is potential for excessive interference into the passive sensors from these GSO satellites. This would be dominated by energy scattered from terrestrial targets into

* Radiocommunication Study Group 7 made editorial amendments to this Recommendation.

the receiving antennas of these passive sensors. The level of interference is affected by: the individual GSO pfd; number of simultaneous GSO systems; methods of frequency reuse within the FSS; the reflectivity of the terrain as characterized by the terrain scattering coefficient; and the mode of operation of the spaceborne sensor. In the United States of America, passive sensors have a primary allocation in the 18.6-18.8 GHz band. The United States of America limits the FSS pfd to $-101 \text{ dB(W/(m}^2 \cdot 200 \text{ MHz))}$. Internationally, passive sensors have a primary allocation in Region 2 and secondary allocations in Regions 1 and 3. RR Table S21.4 limits FSS pfd to $-92 \text{ dB(W/(m}^2 \cdot 200 \text{ MHz))}$ at low elevation angles up to $-82 \text{ dB(W/(m}^2 \cdot 200 \text{ MHz))}$ and higher elevation angles.

Consequently, there is a potential of pfd from the FSS from $-101 \text{ dB(W/(m}^2 \cdot 200 \text{ MHz))}$ to $-82 \text{ dB(W/(m}^2 \cdot 200 \text{ MHz))}$ globally. Since the spaceborne passive sensors would be exposed only intermittently to scattered energy from FSS coverage areas, it is of interest to determine the rate of occurrence of excessive interference events. Recommendation ITU-R RS.1029 states that in shared frequency bands (except in the absorption bands), the interference levels given above ($-155 \text{ dB(W/100 MHz)}$ for 18.6-18.8 GHz) can be exceeded for less than 5% of all measurement cells within a sensor's service area in the case where the loss occurs randomly, and for less than 1% of measurement cells in the case where the loss occurs systematically at the same locations.

The objective of this work is to identify the areas of excessive interference for the different levels of potential FSS pfd. The criteria from Recommendation ITU-R RS.1029 indicate the appropriate metric for interference depends on the particular sensor application and the nature of the interference that occurs. Herein, we report estimates for both conditional events (rate of occurrence given the spaceborne sensor is within a FSS coverage area) and unconditional events (rate of occurrence globally).

A secondary goal is to evaluate potential interference mitigation techniques and to describe a potential method of mitigating interference by avoiding geometry where the sensor might be pointed directly, or nearly so, into a specular reflection. It has been suggested that additional mitigation could be achieved by restricting the sensor scan range from $\pm 70^\circ$ to $\pm 35^\circ$. Both methods were evaluated for a specific case of 4, 8, and 16 GSO systems in the FSS simultaneously serving a coverage area described with 24 spot beams.

The approach was to make use of Monte-Carlo simulations where the interference into a spaceborne sensor is estimated as it orbits the Earth. The motion of the GSO satellites, the Earth, and the spaceborne sensor are all accounted for. Since the scattering of energy from the Earth's surface is a random phenomenon (due to independent fading effects and terrain variability), this variability is also included in the simulation. At each simulation time instant, the interference from all 16 satellites was accounted for including the weighting by the directivity and angular offset of the individual spot beams.

2 Interference scenario

It is of interest to estimate a worst-case level of interference into an EESS satellite passive sensor from a maximum constellation of 16 FSS satellite systems that each provides a common coverage area that is described by 22 conterminous beams and two nearby, but geographically separate beams. Each of the systems uses four times frequency segmentation to minimize intra-system interference. The 16 satellite systems are then grouped by systems of four that offset their segmentation choices to further minimize inter-system interference. Further reduction of mutual interference is achieved by a 2° orbital separation between systems.

Figure 1 illustrates a microwave passive sensing satellite passing over a FSS coverage area and receiving interference from the ground reflections. The sensor makes use of a highly directive receiving beam that is scanned $\pm 70^\circ$ perpendicular to the direction of motion. The sensing area is very small compared to the FSS spot beams that make up the total FSS coverage area. In the simulations performed for this work, the interference is calculated at 2° increments of scan.

As mentioned, each system will segment its spectrum to minimized intra-system interference. Figure 2 illustrates the isolation of four spot beams by such segmentation. The pattern is repeated throughout the coverage area. The next three systems will, it is assumed, stagger the segmentation so the second system, for example, might use F2 in place of F1, F3 in place of F2, etc. Additional systems after the fourth will simply repeat the pattern. Isolation of the systems will be

aided by spatial separation in orbit at 2° increments and use of directive antennas by terrestrial-based users. By this scenario each of the 22 conterminous spot beams will scatter power from four GSOs with spectrum that overlaps that of the EESS, as well as other GSOs that contribute through side lobes that overlap from adjacent beams.

FIGURE 1
16 GSO FSS systems interfering with spaceborne sensor

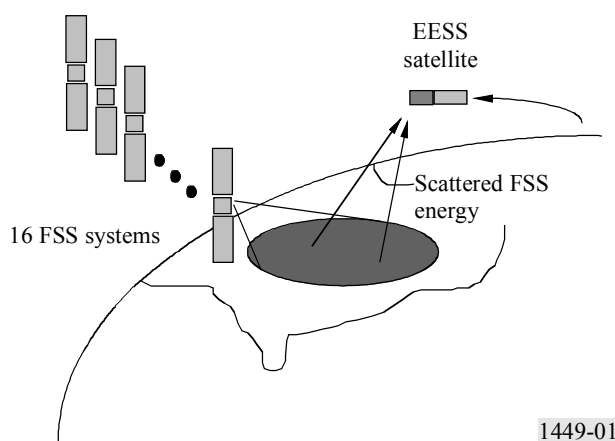
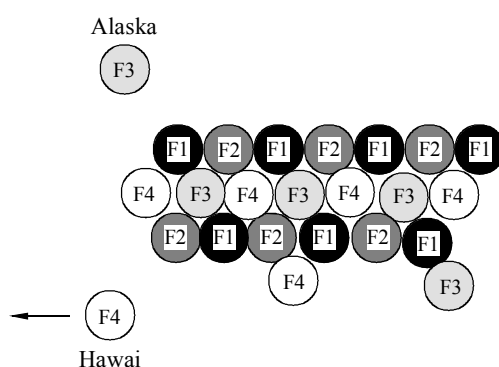


FIGURE 2
Typical FSS coverage, 22 conterminous beams and two off-shore beams



In the event such intra-service interference mitigation techniques are not used, it is possible that all satellites would use identical frequency segmentation. In that case each spot would scatter energy from 16 satellites. However, since the spots would still have the F1-F4 allocation pattern, only a subset of these spots would scatter energy that overlapped the EESS band. In the scenario shown in Fig. 2 this could range from 5 to 7 spot beams depending on the selections of F1-F4 segments.

A set of typical characteristics for the FSS and EESS systems are described in Tables 1 and 2 respectively. The scattering coefficient model described in § 3 is used as the basis for estimating the scattered power.

TABLE 1

FSS parameters in the 18.6-18.8 GHz band

Coverage	22 conterminous, 2 off-shore
5 dB beamwidth	1.0°
Maximum antenna gain	46.5 dBi
pdf at surface of the Earth	−101.0 dB(W/(m ² · 200 MHz)) each polarization
Polarization	RHC and LHC each beam
Bandwidth	200 MHz
Frequency reuse	Every fourth beam
Antenna pattern	Recommendation ITU-R S.672 with $L_N = -25$ dB and $L_F = 0$ dBi

TABLE 2

Spaceborne passive sensor parameters in the 18.6-18.8 GHz band

Orbital altitude	500 km	
Orbital inclination	90.0°	
Boresight elevation angle	−45.0°	
Antenna pattern	dBi	Off-axis angle, θ
	57.0	$\theta \leq 0.2^\circ$
	21.0	$0.2^\circ < \theta \leq 5.5^\circ$
	−14.0	$5.5^\circ < \theta \leq 90.0^\circ$
	−17.0	$\theta > 90.0$
Antenna scan angle	$\pm 70^\circ$	
Polarization	Linear	
Receiver reference bandwidth	100.0 MHz	
Interference threshold	−155 dB(W/100 MHz)	
Along scan spatial resolution	2 km	
Across scan spatial resolution	2 km	
Circular to linear polarization loss	1.5 dB	
Basis for scattering estimates	Skylab/University of Kansas, backscatter curve fits and facet theory (see § 3)	

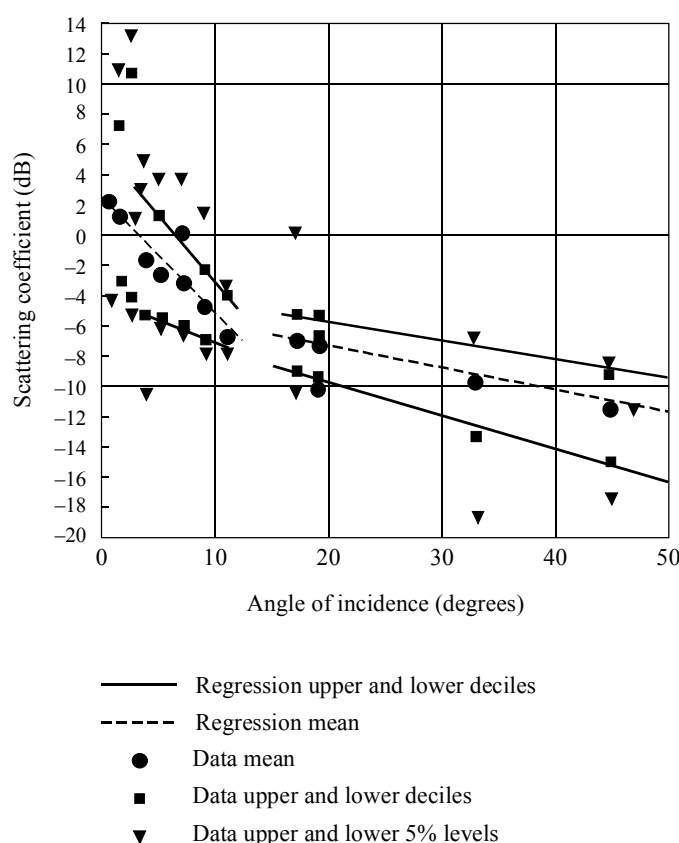
3 Scattering model

A critical parameter affecting the level of interference into a spaceborne sensor is the terrestrial reflectivity as indicated by the scattering coefficient of the terrain being viewed by the sensor. This can result in energy being scattered backwards toward its GSO FSS source and being intercepted by a spaceborne sensor that is moving away from the GSO nadir. Alternatively, the energy can be scattered forward and intercepted by a sensor that is moving toward the GSO nadir. There is much more data on backscatter phenomena than for the forward scatter case. Herein we attempt to make use of available backscatter data and extrapolations, and to infer from these the forward scatter effects.

3.1 Backscatter coefficients

Several methods have been proposed in open literature for modelling the mean and extreme values for backscattering coefficients. Scatterometer data from Skylab, as shown in Fig. 3, indicate a dependence on incidence angle that varies rapidly over the range of 0-10°. The maximum is at 0° incidence.

FIGURE 3
Data from Skylab S-193 scatterometer



Regression lines shown for mean $0^\circ < \theta < 11^\circ$, $17^\circ < \theta < 45^\circ$.
Deciles $3.5^\circ < \theta < 11^\circ$, $17^\circ < \theta < 45^\circ$.

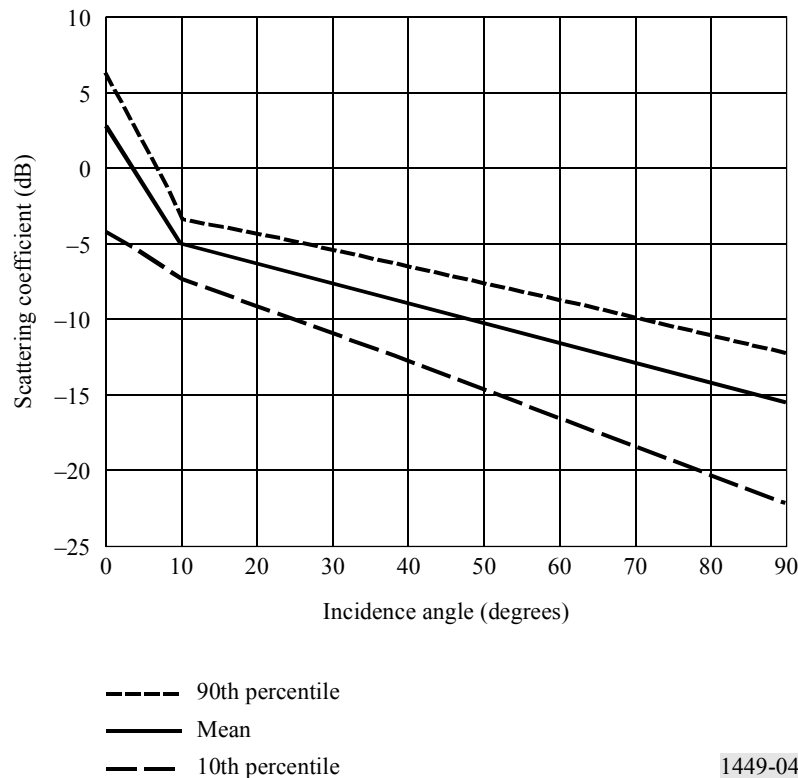
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Beyond 10° incidence, the scattering coefficient continues to decrease but at a significantly slower rate. The region from 0-10° is regarded as a surface specular response, whereas the region beyond is regarded as a surface diffuse response. Since the Skylab data is a composite of many surface types, the different regions cannot be associated with any particular type. Curve fits are shown for the mean as well as the 10th and 90th percentiles. Note that the upper and lower

percentiles are not symmetric with the mean. Also note the width of the percentile range is a maximum at normal incidence and diminishes to a minimum at about 10° incidence. At that point it gradually increases out to 50° incidence. At normal incidence the mean is slightly more than 2 dB. The fit to the upper percentile would suggest a value of about 6 dB at normal incidence.

Several models have also been proposed for statistical distributions of the backscatter coefficients. When a sensor beam is filled with homogeneous terrain, an appropriate model for the received signal using a square law detector is an exponential probability density. For complex terrain, the log-normal probability density and variations have been proposed. Since the Skylab data represents a composite of many types of terrain (the entire United States of America territory), the log-normal density is made use of herein to approximate the statistical distribution of the scattering coefficient. The mean of the scattering coefficient is extrapolated from the Skylab and other available data. The log-normal parameters are inferred by assuming a log-normal process that produces the extrapolated mean and replicates the Skylab observed variability. The resulting mean and percentiles of the scattering coefficient are shown in Fig. 4. As noted before, the percentiles are not symmetrically disposed about the mean. Also, the absolute levels do not differ greatly from the Skylab measurements at 13.9 GHz.

FIGURE 4
Scattering coefficient model for 18.6-18.8 GHz
(Mean and percentiles)

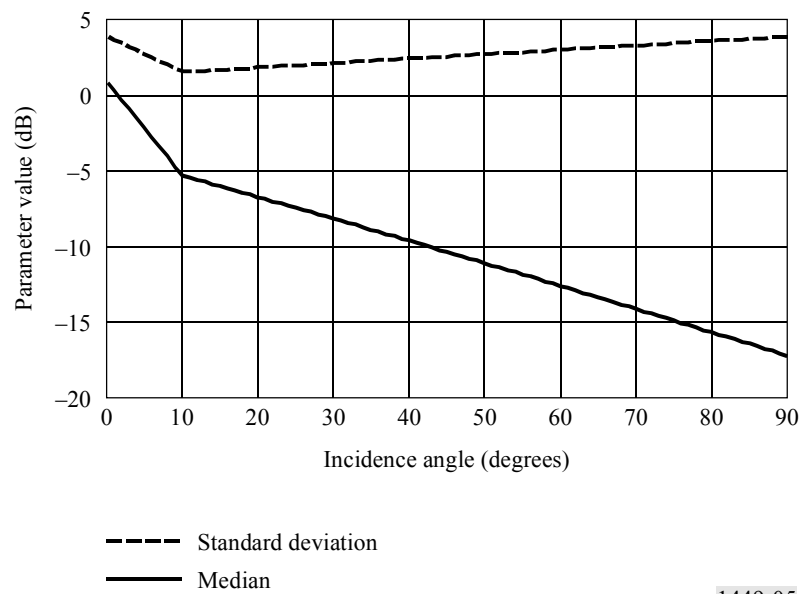


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Figure 5 illustrates the log-normal parameters necessary to fit the extrapolated mean and variability at 18.6-18.8 GHz. The derived median is close to the mean but it is not the same, nor need it be. The standard deviation is near 4 dB at 0° incidence, a minimum at about 10° incidence and gradually increases to about 4 dB at 90° incidence.

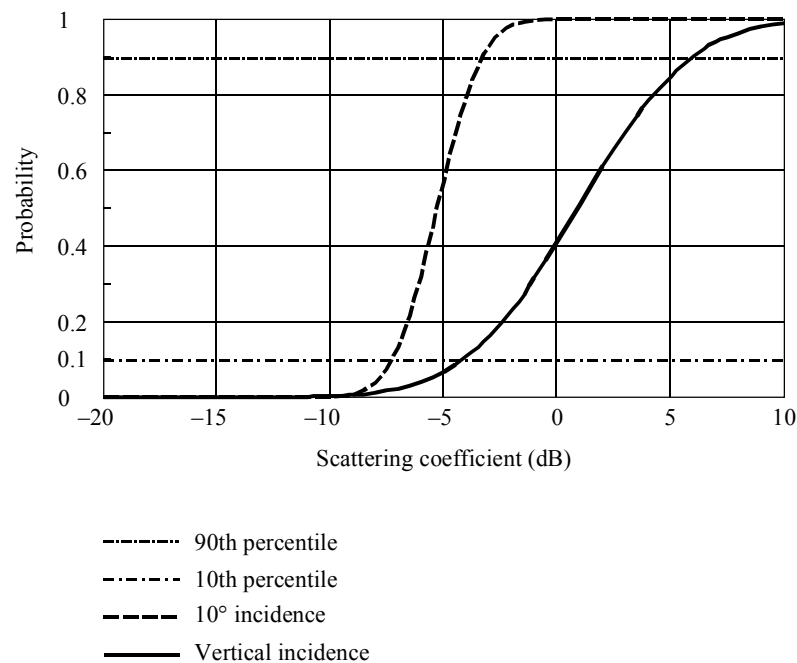
Using these parameters, the scattering coefficient would have the approximate cumulative distributions as shown in Fig. 6. While at normal incidence, the upper percentile is near 6 dB. The upper percentile at 10° incidence is considerably less, near -4 dB. Since the spaceborne passive sensor will be designed to view the Earth at oblique angles near 40° , one can see from the trends in Figs. 5 and 6 that the upper percentile could be considerably less than what one would expect at normal incidence.

FIGURE 5
Log-normal parameters of distribution at 18.6-18.8 GHz



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FIGURE 6
Cumulative distribution of scattering coefficient at normal and 10° incidence



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3.2 Bistatic scattering coefficients

It has been suggested that one could create a bistatic scattering coefficient model from backscatter data by assuming the surface of the Earth could be approximated by an array of flat facets. This makes use of a geometric optics approximation where the reflected rays are treated as line segments.

Figure 7 shows an incident ray impinging on a facet oriented at an angle Φ_x with respect to the vertical. The normal to this facet bisects the included angle between the incident and scattered ray. The percentage of facets with such an orientation would be indicated by the previous backscatter relation at the angle Φ_x . Hence, for a (Φ_i, Φ_s) pair, we get the corresponding scattering coefficient by extracting that value from the data fit at an intermediate angle corresponding to Φ_x . From the geometric relation above:

$$\Phi_x = (\Phi_i - \Phi_s) / 2$$

If we redefine Φ_s as:

$$\Phi_s = \Phi_i + \Delta\Phi_s$$

then Φ_s is viewed as being referenced to the specular direction, which is identical to the incidence angle, Φ_i .

Substituting the modification, then:

$$\Phi_x = -\Delta\Phi_s / 2$$

that is, Φ_x has a magnitude of one-half the amount by which Φ_s differs from the specular angle. Also, the direction of Φ_x is opposite to that of $\Delta\Phi_s$, being negative if Φ_s exceeds Φ_i , and positive if Φ_s is less than Φ_i .

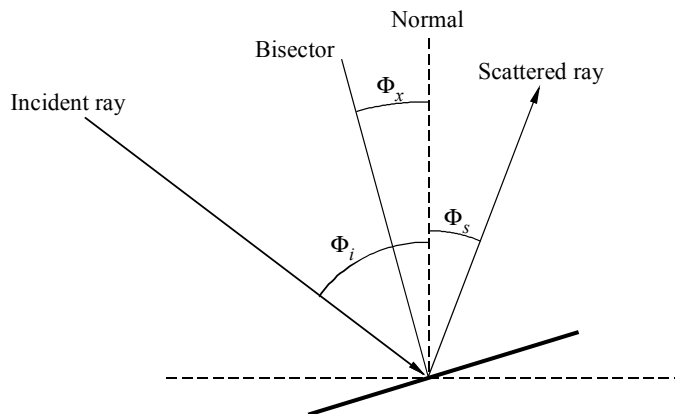
Thus we can estimate the forward scattering coefficient, as referenced to the specular direction, as:

$$\sigma_s(\Delta\Phi_s) = \sigma_0(-\Delta\Phi_s / 2)$$

where σ_s is the desired scattering coefficient and σ_0 is the reference backscatter coefficient (σ_s and σ_0 are conventional symbols for the scattering coefficient and should not be confused with the standard deviation used in previous sections). Note that for $\Phi_s = \Phi_i$, Φ_x is always zero and the corresponding σ_0 is that which occurs at the peak of the backscatter relation, that is, always corresponding to the number of facets at zero elevation. Also, when $\Phi_s = -\Phi_i$ ($\Delta\Phi_s = -2\Phi_i$ and the scattered direction is coincident with the incident direction) $\Phi_x = \Phi_i$, and σ_0 is that value corresponding to the backscatter angle Φ_i , as it should. For other cases, the scattering coefficient in the forward direction at an angle $\Delta\Phi_s$ from the specular direction is the same as the backscatter coefficient at half that angle from the normal. For example, from the equation above, the forward scattering coefficient at 90° from the specular direction would be the same as the backscattering coefficient at 45° from the vertical.

With a symmetrical backscatter relationship, the forward scatter relation can be obtained simply as the backscatter relation centred about the specular direction and with its angular axis doubled.

FIGURE 7
Geometric optics approximation of ground echo in the plane-of-reflection



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We can extend this process to the out-of-plane direction. Figure 8 illustrates the case where a portion of the incident power is scattered out-of-plane. $\vec{V}_i$ is a unit vector pointing in the direction from which the incoming radiation arrives. $\vec{V}_s$ is a unit vector pointing in the direction of the sensor bearing satellite. $\vec{V}_{bi}$ lies in the plane of $\vec{V}_i$ and $\vec{V}_s$ and bisects the included angle between the two. The facets determining the power reflected in the forward $\vec{V}_s$ direction would be