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**A Description of the SNL Clutter Model
Developed for the SRIM Code version 2.2s**

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Abstract

This report describes the clutter model developed at Sandia National Laboratories for the SRIM code version 2.2s. The SNL clutter model is a fully polarimetric model that includes both coherent and incoherent scattering effects. The input parameters to the SNL clutter model are chosen so that an acceptable match is obtained between the model predicted data and the appropriate experimental data. These input parameters are then used in the SRIM code to simulated the desired clutter type.

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Introduction

The Simulated Radar IMage (SRIM) code can be logically divided into two parts: GIFT which is a ray tracing routine and RADSIM which is an electromagnetic calculation routine. GIFT uses ray tracing to sample the target and local clutter scene. It accomplishes this by firing rays from the so-called emanation plane, i.e., the plane from which rays emanate. The emanation plane is parallel to the family of plane waves generated by the radar. So the line-of-sight of the radar is normal to the emanation plane. RADSIM associates with each ray a phasor weighting coefficient (p.w.c.). When the ray intersects a particular surface its p.w.c. is modified according to the scattering properties that have been assigned to that type of surface. The relationship between the incident and scattered p.w.c.'s, see Figure 1, is given by

$$pwc_j = r(\hat{u}_i, \hat{u}_s) e^{i\psi(\hat{u}_i, \hat{u}_s)} \cdot pwc_{j-1} \quad j = 1, 2, \dots \quad (1)$$

where $re^{i\psi}$ defines the scattering properties of the surface and is a function of the incident, $\hat{u}_i$, and scattered, $\hat{u}_s$, directions, and $pwc_0 = 1$.

Figure 1: Relation Between Incident and Scattered Phasor Weighting Coefficients

In this report we will consider how the p.w.c. is modified when it intersects the clutter plate. In particular, we consider the clutter model de-

veloped at Sandia National Laboratories (SNL) for the SRIM code version 2.2s. A discussion of the older clutter model (termed the eps/rho clutter model) is given as background for this new clutter model, called the SNL clutter model.

Persons interested in simply applying the SNL clutter model to a particular problem should skip directly to **Using the SNL Clutter Model in the SRIM Code** on page 21.

Clutter Level Adjustment

When a ray intersects the clutter plate and there is unobstructed line-of-sight (l.o.s.) to the emanation plane, two rays are created at the intersection point, see Figure 2. Note that the specular direction is defined by $\hat{u}_0 = \hat{u}_i - 2(\hat{u}_i \cdot \hat{n}_s)\hat{n}_s$. One ray extends, in the specular direction, to the next intersection point. The other ray extends to the emanation plane. We note that the incident and specular rays must lie in the same plane while the ray extending to the emanation plane has no such constraint. The p.w.c. is modified at this intersection point according to the type of clutter being modeled and the clutter model being used. The amplitudes of the p.w.c.'s for the scattered rays are modeled by a Rayleigh random variable and their phases are modeled as a uniformly distributed random variable.

Now consider single bounce returns to the emanation plane, i.e., $j = 1$. The relationship, as defined in SRIM, between these p.w.c.'s and the differential scattering coefficient (DSC), σ° , observed in an output image is

$$\sigma^\circ = \gamma_e \cos \theta_i, \quad (2)$$

where θ_i is the angle of incidence and γ_e , a measure of the clutter surfaces scattering effectiveness [Barton 1988], is

$$\gamma_e = \{scale \cdot r(\hat{u}_i, \hat{u}_e)\}^2. \quad (3)$$

The scale factor *scale* is dependent on clutter model and *r* is the scattering amplitude to emanation plane and is dependent on clutter level and clutter model. By adjusting *r* in (3) one can effectively control the clutter level, i.e., σ° .

Figure 2: Scattering Geometry at an Intersection Point

In the specular direction γ_0 is defined as

$$\gamma_0 = scale \cdot r(\hat{u}_i, \hat{u}_0), \quad (4)$$

where *scale* is a scale factor dependent on clutter model and *r* is the scattering amplitude in the specular direction that is dependent on clutter level and clutter model. This scattering amplitude controls the amount of power scattered in the specular direction and, in the SRIM code, is *relative* to that value for a flat plate.

The eps/rho Clutter Model

The eps/rho clutter model allows the user to independently choose how the p.w.c.'s are modified for rays in the specular and l.o.s. directions. In the specular direction we have

$$r(\hat{u}_i, \hat{u}_0) = rho \quad (5a)$$

$$\Psi(\hat{u}_i, \hat{u}_0) = \text{Uniform}(0, 2\pi) \quad (5b)$$

$$scale = \frac{\sqrt{\pi}}{2}(1 - absorb) \quad (5c)$$

where ρ is a user supplied parameter. In the l.o.s. direction we have

$$r(\hat{u}_i, \hat{u}_e) = eps \quad (6a)$$

$$\Psi(\hat{u}_i, \hat{u}_e) = \text{Uniform}(0, 2\pi) \quad (6b)$$

$$scale = \frac{2\sqrt{\pi}}{\lambda}(1 - absorb)\sqrt{A_e \sin \theta_i} \quad (6c)$$

where eps is a user supplied parameter and A_e is the area of a ray tube in the emanation plane. The appropriate value of eps is determined by specifying σ^o at a given angle of incidence then using (2), (3), and (6). The $absorb$ parameter in (5c) and (6c) is a clutter switch, i.e., when $absorb = 0$ the clutter is turned on and when $absorb = 1$ the clutter is turned off. When describing the properties of the clutter plate, other values of $absorb$ have no meaning.

There is no satisfactory algorithm to estimate the appropriate value of ρ . The following guideline for determining ρ should generally apply. If the surface is very smooth relative to the radar wavelength, then $\rho > eps$; otherwise $\rho \leq eps$. Table 1 contains typical values of the monostatic DSC, taken from [Stiles 1978], and their corresponding values of eps and ρ for $\lambda = 2\text{cm}$, $A_e = 1\text{cm}^2$. The format of the input parameter list necessary to use the eps/ρ clutter model is given in Appendix II.

The SNL Clutter Model

One may readily conclude that the target signature, predicted by the SRIM code, will be a function of the local clutter type. So the ground/target interaction, predicted by the SRIM clutter model, could potentially change the target signature. It is therefore necessary to model this interaction correctly. We note that once the eps and ρ parameters are chosen, they remain constant and independent of the scattering geometry for all interactions with the clutter plate. This implies that the ground/target interaction is incorrectly modeled in the eps/ρ clutter model. It would also be desirable to relate the eps and ρ values to some physical attributes of the

θ	Tall Grass			Compact Dirt			Dry Concrete		
	σ° (dB)	<i>eps</i>	<i>rho</i>	σ° (dB)	<i>eps</i>	<i>rho</i>	σ° (dB)	<i>eps</i>	<i>rho</i>
20	-6	.4988	.480	-5	.5597	.540	-15	.1770	.650
25	-6	.4569	.440	-5	.5126	.500	-18	.1148	.600
30	-6	.4297	.410	-6	.4297	.410	-18	.1079	.570
35	-6	.4125	.400	-7	.3677	.350	-20	.0823	.540
40	-6	.4029	.390	-9	.2853	.270	-21	.0717	.420
45	-7	.3564	.340	-9	.2831	.270	-22	.0634	.390
50	-7	.3592	.340	-10	.2542	.240	-24	.0507	.360
55	-8	.3277	.310	-10	.2603	.250	-25	.0463	.330
60	-9	.3042	.290	-11	.2417	.230	-26	.0430	.300

Table 1: Typical *eps*/*rho* clutter model parameters

clutter being modeled. These observations were the impetus for developing a new clutter model.

To begin a description of the SNL clutter model it is necessary to acknowledge that the electromagnetic (EM) field scattered by terrain can be written as the sum of incoherent and coherent components, [Ishimaru 1978]. The power contained within each of these components is termed the incoherent and coherent scattered power, respectively.

The EM field scattered from most types of terrain contains both coherent and incoherent components. In general, one or the other of these components dominate for given angles of incidence. The coherent component results primarily from the presence of the terrain surface and is most noticable in the specular direction; especially when the surface is relatively exposed and smooth (relative to the wavelength of the incident EM field). The incoherent component results primarily from multiple bounce interactions (volume scattering) due to heavy vegetation or a rough surface.

In the discussion that follows two models will be introduced. The first model is based upon scattering from an ensemble of dipoles and is used to predict the incoherent component of the scattered power. The other model is based upon scattering from a rough surface and is used to predict

the coherent scattered power. These two models will then be combined into a more generally applicable model from which the appropriate value of $r(\hat{u}_i, \hat{u}_s)$ (the scattering amplitude) are determined and used in the SRIM code.

A Model for the Incoherent Component of the Scattered Power

The incoherent component of the scattered power is modeled by scattering from a slab filled with noninteracting dipoles. The slab has thickness L and is of infinite extent in the xy -plane. The strength of an individual dipole is denoted by b and their density in the slab is denoted by ρ . This model is best suited to terrain that scatters power incoherently, i.e., the phase of the scattered field is best modeled as a random variable. One example of this type of terrain is that for which the scattered field results predominantly from multiple bounce interactions (volume scattering), e.g., heavily vegetated terrain.

The idea of modeling EM scattering by a dipole filled slab was used by [Peake 1959] to model EM scattering from terrain and then much later by [van Zyl 1986] to model the differential scattering coefficient (DSC) of various types of terrain. Both of these references describe the techniques involved in deriving the DSC of a dipole filled slab; only an outline of the procedure is given here.

To start, the orientation of a dipole can be described in spherical coordinates by the two angles (θ_d, ϕ_d) . Since the strength of each dipole is denoted by b ; the bistatic scattering matrix in an h, v basis and relative to the *magnetic* field becomes, see [Lee, 1988],

$$\tilde{S}(\hat{u}_i, \hat{u}_s) = b \begin{pmatrix} -Z_i Z_s & W_i Z_s \\ Z_i W_s & -W_i W_s \end{pmatrix},$$

with

$$W_x = \sin \theta_d \sin(\phi_d - \phi_x),$$

$$Z_x = \sin \theta_x \cos \theta_d - \cos \theta_x \sin \theta_d \cos(\phi_d - \phi_x),$$

where $x = i, s$. Now we assume the orientation of each dipole to be a random variable over the unit sphere. In particular, the dipole axes are assumed to be randomly oriented about the vertical direction and distributed

according to the p.d.f.

$$f(\theta_d, \phi_d) = \frac{3}{4\pi} \cos^2 \theta_d,$$

where $0 \leq \phi_d \leq 2\pi$ and $0 \leq \theta_d \leq \pi$.

A relation between the DSC and the scattering matrix is now needed. Furthermore, since the scattering matrix does not include attenuation effects we anticipate the need to modify this relation in order to incorporate such effects. The following relations, from [Ulaby, 1990], can now be used.

$$\sigma_{RT}^o(\hat{u}_i, \hat{u}_s) = \frac{4\pi}{A} (1 - e^{-2(c_{RT})\rho L}) \langle |\vec{p}^R \cdot \vec{S}(\hat{u}_i, \hat{u}_s) \vec{p}^T|^2 \rangle. \quad (7)$$

In this equation the transmit and receive polarization vectors are $\vec{p}^T$ and $\vec{p}^R$, respectively, while A denotes the illuminated area. An attenuation factor has been incorporated into the terminology to account for attenuation effects. The factor c_{RT} is proportional to the *effective area* of an individual scatterer, see [Papas, 1965]. By defining the ensemble average in (7) as

$$\langle g(\theta_d, \phi_d) \rangle = \iint_{\Omega_d} g(\theta_d, \phi_d) f(\theta_d, \phi_d) d\Omega_d,$$

the polarimetric DSC can be calculated and is given below.

$$\bar{\sigma}_n^o(\hat{u}_i, \hat{u}_s) = G(\theta_i, \theta_s) \begin{pmatrix} a_{hh}(\hat{u}_i, \hat{u}_s) & a_{hv}(\hat{u}_i, \hat{u}_s) \\ a_{vh}(\hat{u}_i, \hat{u}_s) & a_{vv}(\hat{u}_i, \hat{u}_s) \end{pmatrix}. \quad (8)$$

The functions G , a_{hh} , a_{hv} , a_{vh} , and a_{vv} are quite lengthy, and are given in Appendix I. The components of (8) are simply the polarimetric components of the DSC, e.g.,

$$\sigma_{hh}^o(\hat{u}_i, \hat{u}_s) = G(\theta_i, \theta_s) a_{hh}(\hat{u}_i, \hat{u}_s),$$

and similarly for the other components. As suggested by (8), this incoherent model is a fully polarimetric model, i.e., it does predict the HH, VV, HV, and VH behavior of the DSC. It also predicts the generally observed trend that the co-polarized monostatic DSC has a larger value than does the cross-polarized monostatic DSC. The co-polarized and cross-polarized

DSC's predicted by this model are correlated, i.e., if one is increased or decreased, then the other increases or decreases in a similar manner.

Using (8) we can now calculate the incoherent component of the monostatic DSC predicted by the dipole scattering model. In doing so, the parameters inherent to this model (b, L, ρ) are adjusted to give good agreement with the measured incoherent component of the monostatic DSC data for the type of terrain under consideration, see Figure 3 and 4. Observe that the incoherent scattering model predicts quite well the overall behavior of the DSC for both cases shown. This implies that at 17GHz the EM field scattered from tall grass and loose dirt is predominantly incoherent.

A Model for the Coherent Component of the Scattered Power

The dipole scattering model could predict the monostatic DSC for heavily vegetated terrain and unvegetated rough terrain; both known to incoherently scatter power. We find from studying monostatic DSC curves, [Stiles 1978], that most natural terrain and some manmade surfaces scatter power incoherently except near the specular direction, see Figures 5a and 6a. It is near the specular direction where the dipole scattering model generally fails to predict the behavior of the DSC. The reason for this is that coherent scattering usually dominates near the specular direction. Again, when incoherent scattering dominates, the dipole scattering model would generally predict the correct behavior of the DSC.

Coherent scattering is generally due to the presence of the terrain surface. Consequently, scattering from a rough surface is used to model the coherent scattering component. The surface is assumed to be perfectly conducting and very gently undulating with the height, $z = g(x, y)$, distributed as a jointly exponential random variable with zero mean and variance $\langle z^2 \rangle$.

We assume the following polarimetric form for the bistatic DSC of a rough surface,

$$\sigma_c^o(\hat{u}_i, \hat{u}_s) = \sigma_{maz}^o f_r(R, \Delta) f_i(\hat{u}_i, \hat{u}_s) \begin{pmatrix} \cos^2 \theta_s \cos^2(\phi_i - \phi_s) & \cos^2 \theta_s \cos^2 \theta_i \sin^2(\phi_i - \phi_s) \\ \sin^2(\phi_i - \phi_s) & \cos^2 \theta_i \cos^2(\phi_i - \phi_s) \end{pmatrix}. \quad (9)$$

This result was, in part, obtained from the bistatic scattering matrix of a finite-dimensional horizontally-oriented flat plate using the physical optics

Figure 3: Monostatic DSC of .8m Tall Grass @17GHz from a) [Stiles 1978] and b) Incoherent Scattering Model(VV-polarization)

Figure 4: Monostatic DSC of Loose Dirt @17GHz from a) [Stiles 1978] and b) Incoherent Scattering Model(VV-polarization)

Figure 5: Monostatic DSC of Dry Asphalt @ 17GHz from a) [Stiles 1978] and b) SNL Clutter Model(VV-polarization)

approximation for the induced current on the plate. The constant σ_{maz}^o corresponds to the DSC, at normal incidence, of a perfectly conducting flat plate of finite dimension. The phase integration term, f_i , is given by

$$f_i(\hat{u}_i, \hat{u}_s) = \text{sinc}^2(2 \cdot hspace \cdot w(\theta, \phi)/\lambda) \text{sinc}^2(2 \cdot lspace \cdot w(\theta, \phi)/\lambda \cos \theta_i)$$

with

$$w(\hat{u}_i, \hat{u}_s) = \sin \theta_s \cos \phi_s - \sin \theta_i \cos \phi_i.$$

The function f_r is determined by first noting that [Brown 1982] gives the following result for the coherent power scattered in the specular direction from a perfectly conducting rough surface relative to a perfectly conducting flat plate.

$$\frac{|\langle \bar{H}_s \rangle|^2}{|\bar{H}_s^o|^2} = \frac{1}{(1 + \frac{4}{3} R^2)^3},$$

where $R = 2\pi \sqrt{\langle z^2 \rangle} \cos \theta_0 / \lambda$ is the Rayleigh (roughness) parameter and (θ_0, ϕ_0) is the specular direction. So it is plausible to choose f_r as

$$f_r(R, \Delta) = \frac{g(R, \Delta)}{(1 + \frac{4}{3} R^2)^3}, \quad (10)$$

where the function g determines the shape of the coherent component of the scattered power and $\Delta = |\hat{u}_s - \hat{u}_0|$. Based upon the behavior of empirical data near normal incidence we assume this function to have the form

$$g(R, \Delta) = 10^{-\Delta/R}, \quad (11)$$

and require $\Delta = \alpha R$ (α dependent upon R) so that $\Delta/R < \infty$ as $R \rightarrow 0$. In this manner we define a solid angle centered about the specular direction. Any ray scattered outside this solid angle is assumed to have negligible contribution and is assigned a p.w.c. of zero. We anticipate that for smooth surfaces ($R < .5$), σ^o will be extremely peaked about the specular direction and less so for relatively rough surfaces ($R > 1.5$). In fact, [Brown 1982] has shown that when $R > 1.5$ the scattered power is predominantly incoherent in the specular direction. In that case it is probably justified to consider only the incoherent scattered power and therefore use only the dipole scattering model.

Figure 6: Monostatic DSC of Compact Dirt @ 17GHz from a) [Stiles 1978] and b) SNL Clutter Model(VV-polarization)

Observe from (9) that in the monostatic, $\theta_s = \theta_i$, $\phi_s = \phi_i$, and specular, $\theta_s = \theta_i$, $\phi_s = \phi_i + \pi$, directions no depolarization is predicted. This is a result of the physical optics approximation used to obtain (9).

Combining the Coherent and Incoherent Clutter Models

Scattering from terrain is generally both coherent and incoherent, [Ulaby 1986]. The coherent component is usually significant only near the specular direction while the incoherent component is significant for all directions. The obvious extension is to combine the coherent and incoherent clutter models into a more generally applicable model, called the SNL clutter model. The incoherent component of the scattered field is defined as

$$\rho_n = \Sigma_n e^{j\nu},$$

where Σ_n is a Rayleigh random variable with mean value $\sqrt{\sigma_n^0}$ and ν is a

uniform random variable in the interval $(0, 2\pi)$. The coherent component of the scattered field, denoted by ρ_c , is modeled by a Rayleigh random variable with mean value $\sqrt{\sigma_c^0}$; however, the most appropriate model for this component is still an open question. These two field components are then added vectorially to give $r e^{i\Psi}$, see (1), as

$$r(\hat{u}_i, \hat{u}_s) = \sqrt{\rho_c^2 + |\rho_n|^2 - 2|\rho_n|\rho_c \cos(\pi - \nu)} \quad (12)$$

and

$$\Psi(\hat{u}_i, \hat{u}_s) = \sin^{-1}\left(\frac{|\rho_n|}{r} \sin(\nu)\right). \quad (13)$$

These two functions describe how the p.w.c.'s associated with rays that intersect the clutter plate get modified in the SNL clutter model. They are functions of the SNL clutter model parameters, $(b, L, \rho, \langle z^2 \rangle)$, and the relative scattering geometry at the intersection point. The appropriate value of $r(\hat{u}_i, \hat{u}_s)$ and $\Psi(\hat{u}_i, \hat{u}_s)$ are samples of (12) and (13) at the angles that define the direction of interest. So in the specular direction we have

$$r(\hat{u}_i, \hat{u}_0) = r(\hat{u}_i, \hat{u}_s = \hat{u}_0) \quad (14a)$$

$$\Psi(\hat{u}_i, \hat{u}_0) = \Psi(\hat{u}_i, \hat{u}_s = \hat{u}_0) \quad (14b)$$

$$scale = 1 \quad (14c)$$

and in the l.o.s. direction we have

$$r(\hat{u}_i, \hat{u}_e) = r(\hat{u}_i, \hat{u}_s = \hat{u}_e) \quad (15a)$$

$$\Psi(\hat{u}_i, \hat{u}_e) = \Psi(\hat{u}_i, \hat{u}_s = \hat{u}_e) \quad (15b)$$

$$scale = \sqrt{\csc \theta_i} \quad (15c)$$

To make analogy with the *eps*/*rho* clutter model described earlier; the quantities *eps* and *rho* are seen to be specific samples of the function $r(\hat{u}_i, \hat{u}_s)$. So the concept of *eps* and *rho* existing as essentially independent quantities is now passé.

Using (2), (3), and (15) we can calculate the monostatic DSC predicted by the terrain scattering model. In doing, the parameters $(b, L, \rho, \langle z^2 \rangle)$ are adjusted to give acceptable agreement with the monostatic DSC data

for the type of terrain under consideration. This is usually done with a simulation program. Once the model parameters have been determined, they are used in the SNL clutter model. This procedure was exercised using the monostatic DSC data shown in Figures 3a, 4a, 5a, and 6a. The results are given in Figures 3b, 4b, 5b, and 6b.

Using the SNL Clutter Model in the SRIM Code

The typical monostatic DSC curve can be divided into three sections--according to the dominant scattering mechanisms at work. The *near normal incidence* region for which coherent scattering (surface type scattering) can play a dominant role. The *plateau* region in which incoherent scattering (volume type scattering) typically dominates. Finally, the *shadow* region (near grazing incidence) in which the behavior of the DSC is least understood, see [Ulaby 1989]. The parameters of the SNL clutter model control the behavior of the DSC as follows. The surface height variance, $\langle z^2 \rangle$, controls the peakedness of the DSC curve near the specular direction. Its allowable range is $\langle z^2 \rangle \in [0, \infty)$. A perfectly flat surface corresponds to $\langle z^2 \rangle = 0$. However, the measure of surface roughness is the Rayleigh parameter described earlier. The effect of $\langle z^2 \rangle$ on the DSC curve is shown in Figure 7. The maximum DSC value, σ_{max}^o , controls the *absolute* peak of the DSC data. Consequently, this parameter is used only as an aid to determining the surface height variance and is not an input parameter in the SNL clutter model. The dipole strength, b , controls the backscatter level in the plateau region. The allowable range of b is $b \in (0, b_{max})$ with $b_{max} \simeq 5\sqrt{A_e/\lambda^2}$. The effect that b has on the DSC is shown in Figure 8. The product of the density of the dipoles, ρ , and the depth of the layer, L , will also raise or lower the level of the DSC for any given angle of incidence. This effect is generally less noticable than the others mentioned above.

A SNL clutter model parameter list with corresponding DSC data is given in Table 2. The format of the input parameter list necessary to use the SNL clutter model is given in Appendix II.

Figure 7: Effect of surface height variance on the monostatic DSC a) $\langle z^2 \rangle = 1.0$ and b) $\langle z^2 \rangle = .001$

Summary

The SRIM code clutter modeling environment was introduced along with a discussion of the relationship between the p.w.c.'s and the observed clutter level in a simulation image.

Both the eps/rho clutter model and the SNL clutter model were discussed. The eps/rho clutter model can be thought of as a zero-order approximation to the clutter scattering phenomenon, i.e., one for which the scattering amplitudes are independent of the scattering geometry. The SNL clutter model, however, is an evolutionary extension of the eps/rho clutter

Figure 8: Effect of the dipole strength on the monostatic DSC a) $b = .2$ and b) $b = .7$

Parameter List					Corresponding DSC Data
σ_{max}^o	b	ρ (cm ⁻³)	L (cm)	$\langle z^2 \rangle$ (cm ²)	
9	.7	1000	100	.1	Tall Grass: Figure 3
9	.7	1000	100	.1	Loose Dirt: Figure 4
630	.8	1000	100	.0005	Dry Asphalt: Figure 5
12	.8	1000	100	.035	Compact Dirt: Figure 6
12	.6	1000	100	.015	Dry Snow on Compact Dirt: Figure 9
6	.2	1000	100	.025	Wet Snow on Compact Dirt: Figure 10
4	.75	1000	100	.02	Dry Snow on Grass: Figure 11
3	.35	1000	100	.025	Wet Snow on Grass: Figure 12
9	.35	1000	100	.1	Benign Clutter Background: Figure 13

Table 2: Parameter List for SNL Clutter Model

model. It models both coherent and incoherent scattering phenomenon as a function of the scattering geometry. The SNL clutter model is also a fully polarimetric model since it predicts the HH, VV, HV, and VH behavior of the DSC.

Several examples demonstrating the usage of the SNL clutter model were given along with necessary information on how to invoke the model in a SRIM environment.

Figure 9: Monostatic DSC of Dry Snow on Compact Dirt @17GHz from a) [Ulaby 1979] and b) SNL Clutter Model(VV-polarization)

Figure 10: Monostatic DSC of Wet Snow on Compact Dirt @17GHz from
a) [Ulaby 1979] and b) SNL Clutter Model(VV-polarization)

Figure 11: Monostatic DSC of Dry Snow on Grass @17GHz from a) [Ulaby 1979] and b) SNL Clutter Model(VV-polarization)

Figure 12: Monostatic DSC of Wet Snow on Grass @17GHz from a) [Ulaby 1979] and b) SNL Clutter Model(VV-polarization)

Figure 13: Monostatic DSC for a Benign Clutter Background @15GHz (VV-polarization). (There is no corresponding experimental data.)

Appendix I. Incoherent Scattering Equations

The following equations are used in conjunction with (8) and define the components of the polarimetric DSC for a slab filled with noninteracting dipoles. These equations are used in the SRIM code to compute the incoherent component of the scattered power.

$$\begin{aligned}
 a_{hh}(\hat{u}_i, \hat{u}_s) &= A_{hh} \left([1 + 2\cos^2(\phi_i - \phi_s)] \cos^2 \theta_i \cos^2 \theta_s + 15 \sin^2 \theta_i \sin^2 \theta_s + \right. \\
 &\quad \left. 3[\cos^2 \theta_i \sin^2 \theta_s + \cos^2 \theta_s \sin^2 \theta_i + \cos(\phi_i - \phi_s) \sin(2\theta_i) \sin(2\theta_s)] \right) \\
 a_{hv}(\hat{u}_i, \hat{u}_s) &= A_{hv} \left(3 \sin^2 \theta_s + [1 + 2\sin^2(\phi_i - \phi_s)] \cos^2 \theta_i \right) \\
 a_{vh}(\hat{u}_i, \hat{u}_s) &= A_{vh} \left(3 \sin^2 \theta_i + [1 + 2\sin^2(\phi_i - \phi_s)] \cos^2 \theta_s \right) \\
 a_{vv}(\hat{u}_i, \hat{u}_s) &= A_{vv} [1 + 2\cos^2(\phi_i - \phi_s)]
 \end{aligned}$$

$$A_{hh} = \frac{1 - e^{-2\alpha_{hh}\mu L}}{b_v^s \cos \theta_s + b_v^i \cos \theta_i}$$

$$A_{hv} = \frac{1 - e^{-2\alpha_{hv}\mu L}}{b_h^s \cos \theta_s + b_v^i \cos \theta_i}$$

$$A_{vh} = \frac{1 - e^{-2\alpha_{vh}\mu L}}{b_v^s \cos \theta_s + b_h^i \cos \theta_i}$$

$$A_{vv} = \frac{1 - e^{-2\alpha_{vv}\mu L}}{b_h^s \cos \theta_s + b_h^i \cos \theta_i}$$

$$c_{hh} = \left(\frac{b_v^i}{\cos \theta_i} + \frac{b_v^s}{\cos \theta_s} \right)$$

$$c_{hv} = \left(\frac{b_h^i}{\cos \theta_i} + \frac{b_v^s}{\cos \theta_s} \right)$$

$$c_{vh} = \left(\frac{b_v^i}{\cos \theta_i} + \frac{b_h^s}{\cos \theta_s} \right)$$

$$c_{vv} = \left(\frac{b_h^i}{\cos \theta_i} + \frac{b_h^s}{\cos \theta_s} \right)$$

finally b_k^z, b_v^z ($x = i, s$) and $G(\theta)$ are defined as

$$b_k^z = \frac{3\lambda^2}{80\pi},$$

$$b_v^z = \frac{3\lambda^2}{80\pi} (1 + 2 \sin^2 \theta_z),$$

and

$$G(\theta_i, \theta_s) = \frac{\lambda^2}{2\pi} \frac{\|b\|^2}{35} \cos \theta_i \cos^2 \theta_s.$$

The *monostatic* DSC matrix can be obtained from the equations above by defining $\theta_s = \theta_i$ and $\phi_s = \phi_i$.

Appendix II. Clutter Model Input Parameter List

An example of the input parameter field for the ϵ/ρ clutter model is given below. This field should be the fourth line of the reflection model file.

'4', 0., -15., .2, 14., 0., 0., 0.

In this example the mean value of the DSC is set to -15dB. The corresponding value of ϵ is then calculated and used in the third entry. The value of ρ is set to 0.2 in the fourth entry. The fifth entry, 14., selects the ϵ/ρ clutter model, i.e., model number 4, and clutter fill, the prefix 1. The corresponding example without clutter fill is now given.

'4', 0., -15., .2, 4., 0., 0., 0.

An example of the input parameter field for the SNL clutter model is given below. This field should again be the fourth line of the reflection model file.

'4', .5, 1000., 100., 17., .1, 0., 0.

In this example the following parameter values have been selected: $b = 0.5$, $\rho = 1000$, $L = 100$, and $\langle z^2 \rangle = 0.1$. The fifth entry, 17., selects the SNL clutter model, i.e., model number 7, and clutter fill, the prefix 1. The corresponding example without clutter fill is now given.

'4', .5, 1000., 100., 7., .1, 0., 0.

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