

DIRSIG4 Reflectance Properties

From DirsigWiki

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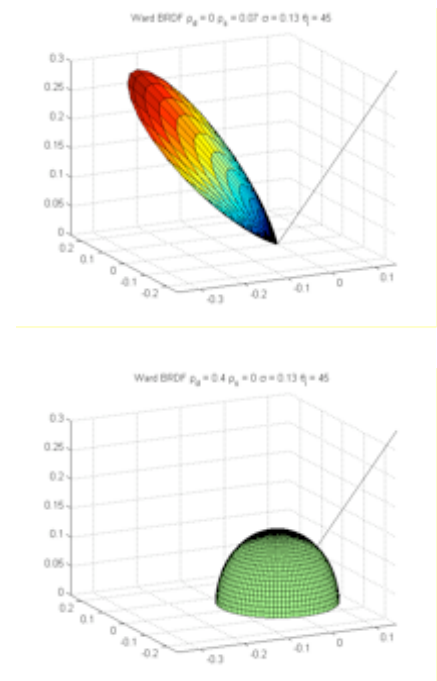
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Introduction

This chapter covers "Reflectance Properties". These characterize surface reflectance as a function of viewer location, source location, and wavelength. Each DIRSIG material can have its own reflectance property assigned.

The reflectance property is used by the "Radiometry Solver" that is assigned to the same material. This radiometry solver determines the energy incident on a surface by sampling the environment. This sampling includes the sun or moon, man-made light sources, the atmosphere, and other scene geometry. The reflectance property is then used to compute the energy reflected from each sample towards the view ray.

The following table lists the available reflectance properties. Each has been cross-verified for correctness against an external implementation. Note that some are marked as "polarized". While this indicates that the model computes polarized reflectances, these models will also work in unpolarized simulations. Likewise, unpolarized models can be used in polarized simulations, but they effect only the total radiance. They leave the degree and angle of polarization unchanged. (That is, they alter only the s_0 component of the reflected stokes vectors).



Name	Description	Polarized	Advantages	Disadvantages
NEF Beard-Maxwell	NEFv9 version of Beard-Maxwell BRDF	No	Many available measurements	Many model parameters
Phong BRDF	Simple analytical BRDF	No	Extremely simple. Many available measurements	Little basis in physics. No spectral component
Priest-Germer	Target material pBRDF	Yes	Few model parameters	
Shell Background	Background material pBRDF	Yes	Spatial variability	Few measurements. Not for target materials
Shell Target	Target material pBRDF	Yes		Few measurements. Experimental
Ward BRDF	Simple analytical BRDF	No	Extremely simple. Many available measurements	Little basis in physics. No spectral component

Materials with these reflectance properties are configured using the DIRSIG4 material database (mat) format. The following example shows an asphalt material using the NEF Beard-Maxwell reflectance property, together with the "Generic Radiometry Solver".

```

MATERIAL_ENTRY {
  NAME = asphalt
  ID = 1

  SURFACE_PROPERTIES {
    REFLECTANCE_PROP_NAME = NEFBeardMaxwell
    REFLECTANCE_PROP {
      NEF_MAT_FILE = /dbmF_05-1/Materials/Single_Materials/0693UUUASP.nmf
    }
  }

  RAD_SOLVER_NAME = Generic
  RAD_SOLVER {
    INITIAL_SAMPLE_COUNT = 25
    MAX_BOUNCES = 2
    SAMPLE_DECAY_RATE = 10
  }
}

```

Note that the reflectance property is defined in the "SURFACE_PROPERTIES" section.

Material Measurements

One of the challenges of working with BRDF models is finding adequate databases of material measurements. A few available sources are:

- **Nonconventional Exploitation Factors (NEF) Database**
 - Data fitted to the NEF Beard-Maxwell BRDF model
 - See the "NEF Beard-Maxwell BRDF" section for more details.
- **Cornell University Program of Computer Graphics**
 - Provides raw measurement data in the visible region
 - <http://www.graphics.cornell.edu/online/measurements/reflectance/>
- **CURet BRDF Measurement Database**
 - Provides raw measurement data in the visible region of 61 samples
 - <http://www1.cs.columbia.edu/CAVE/software/curet/>

DHR Integration

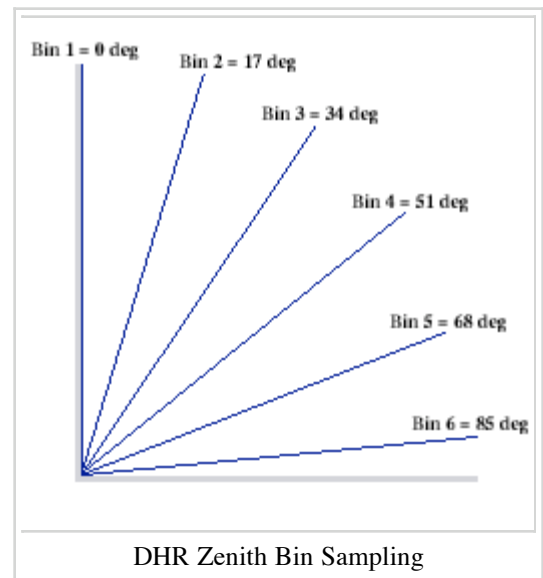
DIRSIG needs the surface emissivity to model self-emitted energy. This information will be derived from the Reflectance Property if the material has no Emissivity Property assigned.

From the Reflectance Property, DIRSIG computes the Directional Hemispherical Reflectance (DHR), which is defined:

$$DHR(\vec{s}, \lambda) = \int_{\Omega_+} BRDF(\vec{s}, \vec{v}, \lambda)(\vec{v} \cdot \vec{n})d\omega_{\vec{v}}$$

where:

- \vec{s} is the view vector.
- λ is the wavelength
- Ω_+ represents the hemisphere of exitant vectors, \vec{v} .
- \vec{n} is the normal vector.
- $d\omega_{\vec{v}}$ is the solid angle in the direction of the exitant vector.



From the DHR, the Directional Hemispherical Emissivity (DHE) is derived using the relation:

$$DHE = 1 - DHR$$

In turn, this DHE is multiplied against the Planck Blackbody ideal exitance to determine the self-emitted energy.

If the DHR is required, DIRSIG will perform (and cache) the integration described above. There are several user-controllable parameters for this integration. These parameters are added directly to the REFLECTANCE_PROP section, and are valid for all the available reflectance property models.

Parameter	Description	Default
-----------	-------------	---------

DHR_NUM_ZENITH_BINS	Number of incident zenith bins, from 0 to max zenith	6
DHR_MAX_ZENITH_ANGLE	Maximum zenith angle in degrees to sample, prevents grazing angle issues	85.0
DHR_INTEGRATION_DPFI	Integration step size in degrees along azimuth	1.0
DHR_INTEGRATION_DTHETA	Integration step size in degrees along zenith	1.0

The diagram shows the default view vector zenith sampling for DHR calculations. The first zenith bin is always at 0 degrees. The last bin is always at DHR_MAX_ZENITH_ANGLE (85 by default). The remaining bins are spread evenly in between.

The following sample shows these DHR parameters applied to a Reflectance Property:

```

-----
REFLECTANCE_PROP_NAME = ShellTarget
REFLECTANCE_PROP {
  BRDF_FIT_FILE = ./GlossyBlackPaint.fit
  EMISSIVITY_FILE = ./GlossyBlackPaint.ems

  DHR_NUM_ZENITH_BINS = 10
  DHR_MAX_ZENITH_ANGLE = 89.0
  DHR_INTEGRATION_DPFI = 0.5
  DHR_INTEGRATION_DTHETA = 0.5
}
-----

```

Reflectance Models

NEF Beard-Maxwell BRDF

Materials from the Nonconventional Exploitation Factors (NEF) database can be used directly in DIRSIG. The NEFDS describes materials using a modified version of the Beard-Maxwell BRDF model. Currently, only version 9 of the NEF database is supported; material files distributed with version 10 will not work.

The NEFDS is a third party product which is not part of the DIRSIG distribution. A government sponsor is needed to gain access to the NEFDS. If a suitable sponsor is available, requests for access may be made to:

```

-----
Ms. Carol May
Cortana Corporation
Suite 200
520 North Washington Street
Falls Church, VA 22046-3538
-----

```

Note that some NEF material files actually come with much of the information needed by THERM. This includes thermal conductivity, specific heat, and mass density. DIRSIG does not automatically parse this information in to a thermal model at this time. However, this information can still be manually added by the

user if desired. The NEF User's Guide details the file format of the materials files and explains where this information can be found.

To use the NEF Beard-Maxwell model with a NEF material file, the material database syntax is as follows:

```
REFLECTANCE_PROP_NAME = NEFBeardMaxwell
REFLECTANCE_PROP {
  NEF_MAT_FILE = /dbmF_05-1/Materials/Single_Materials/0693UUUASP.nmf
}
```

DIRSIG runs with the same permissions as the user invoking it. If the user does not normally have access to the NEFDS material files, those files will still be inaccessible when referenced via a DIRSIG material file.

For more information, consult:

- *NEFDS Beard-Maxwell BRDF Model Implementation in Matlab*, M. Montanaro, Digital Imaging and Remote Sensing Laboratory, Rochester Institute and Technology, June 2007.

Phong BRDF

The simple Phong BRDF is described entirely in the material entry:

```
REFLECTANCE_PROP_NAME = Phong
REFLECTANCE_PROP {
  AMBIENT_REFLECTION_CONSTANT = 0.000
  DIFFUSE_REFLECTION_CONSTANT = 0.015
  SPECULAR_REFLECTION_CONSTANT = 0.015
  SHININESS_CONSTANT = 22
}
```

The model is implemented:

$$\rho = k_a + k_d(L \cdot N) + k_s(L \cdot V)^\alpha$$

where

ρ	Reflectance
k_a	Ambient reflection constant
k_d	Diffuse reflection constant
k_s	Specular reflection constant
α	Shininess constant
L	Vector to source

N	Surface normal vector
V	Vector towards specular direction

Note that there is no spectral variation.

Priest-Germer BRDF

The Priest-Germer BRDF is a simple model providing polarized reflectance calculations. For input, the model needs the slope variance (σ) and the complex index of refraction, as a function of wavelength. This model input is supplied in a separate Parameter File.

DIRSIG has provided several optional additions, detailed in Jason Meyers' PhD thesis. These include a Torrance-Sparrow shadowing function and a precomputed diffuse contribution table.

Parameter	Description
PARAMETER_FILE	Filename for BRDF Model Parameters
ENABLE_POLARIZATION	Indicates whether to calculate polarized or unpolarized reflections
ENABLE_DIFFUSE_CONTRIBUTION	Indicates whether to include DHR-based diffuse contribution
ENABLE_SHADOWING_FUNCTION	Indicates whether to use Torrance-Sparrow shadowing function

A sample specifying the model in the material database:

```

REFLECTANCE_PROP_NAME = PriestGermer
REFLECTANCE_PROP {
  PARAMETER_FILE = ./al-crc-015.TS.brdf
  ENABLE_POLARIZATION = TRUE
  ENABLE_DIFFUSE_CONTRIBUTION = TRUE
  ENABLE_SHADOWING_FUNCTION = TRUE
}

```

As note above, the "ENABLE_DIFFUSE_CONTRIBUTION" and "ENABLE_SHADOWING_FUNCTIONS" are both additions to the original Priest-Germer model. To reproduce the exact behavior of the original Priest-Germer paper, both these options should be set to "FALSE".

The model parameter file has four columns of data:

- First column is wavelength in microns
- Second column is sigma

- Third column is complex index of refraction, real part
- Fourth column is complex index of refraction, imaginary part

A sample parameter file in its entirety:

```

0.53904 0.150 0.826 6.283
0.56354 0.150 1.018 6.846
0.61990 0.150 1.304 7.479
0.66677 0.150 1.741 8.205
0.77487 0.150 2.625 8.597

```

For more information, consult:

- *Modeling Polarimetric Imaging using DIRSIG*, J. P. Meyers, Ph.D. Thesis, Center for Imaging Science, Rochester Institute of Technology, 2002. <http://www.dirsig.org/docs/meyers.pdf>
- *Polarimetric BRDF in the Microfacet Model: Theory and Measurements*, R. G. Priest and T. A. Germer, Proceedings of the 2000 Meeting of the Military Sensing Symposia Specialty Group on Passive Sensors, Vol. 1, 169-181, 2000.

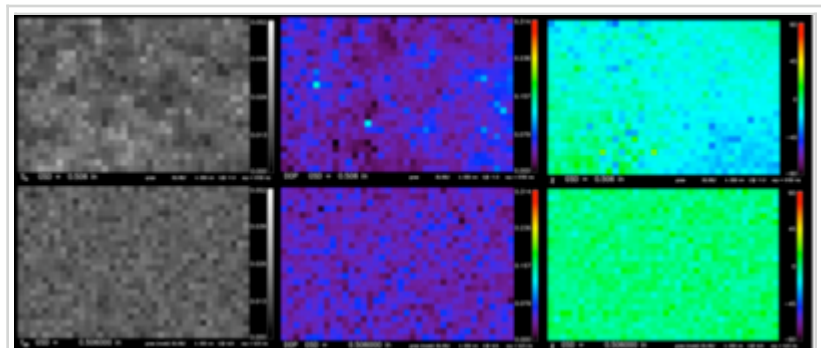
Shell Background BRDF

The polarized Shell Background model is designed for background materials like grass and soil. It provides spatial variability using statistical parameters.

Currently, only three material measurements are available:

- Grass
- Soil
- Asphalt

More information about the measurement process can be found in Shell's thesis.



A comparison of empirical data (top) to synthetic data generated by Background pBRDF model (bottom). Left to right are f_{00} , DOP, and χ

The model is applied in the material database by specifying a fit file and an emissivity file:

```

REFLECTANCE_PROP_NAME = ShellBackground
REFLECTANCE_PROP {
    BRDF_FIT_FILE = ./grass.fit
    EMISSIVITY_FILE = ./grass.ems
}

```

The BRDF_FIT_FILE, described below, indicates the file containing the fit parameters for the BRDF model. The EMISSIVITY_FILE indicates a DIRSIG3 emissivity (ems) file. The first curve from this file

will be converted to reflectance and used by the model.

The fit file is composed of two section types. The variable names used in both cases are identical to those in James Shell's PhD thesis. The first section type, SHARED_FIT_PARAMS, holds the wavelength-independent parameters:

Parameter	Description
RHO_0	The “base” wavelength reflectance factor for DOP spectral interpolation
P1, P2, P3, P4	$DOP_0(\xi)$ polynomial coefficients for “base” band, or that having the highest DOP
PF1, PF2, PF3, PF4	Polynomial coefficients for determining the polarized reflectance fraction $\rho_{pol}(\xi)$
A, B	f_{00} relative (%) variability as a function of GSD
C, D	DOP variability as a function of GSD
E, F	χ variability as a function of GSD

The second section type, FIT_PARAMS, holds wavelength-dependent parameters. Multiple instances of this section may be present in a fit file. The model interpolates between available measurements.

LAMBDA	Wavelength [microns] for fit data
RHO	Directional Hemispherical Reflectance (DHR) for this wavelength
K0, K1, K2	Roujean fit parameters for this wavelength

A complete example fit file follows:


```

SHELL_BACKGROUND = 1.0

SHARED_FIT_PARAMS {
  RHO_0 = 0.075211
  P1 = 1.9582E-03
  P2 = 9.8206E-02
  P3 = -6.6807E-02
  P4 = 1.1251E-02
  PF1 = 9.4574E-04
  PF2 = 2.9314E-03
  PF3 = -1.7853E-03
  PF4 = 2.4078E-04
  A = 0.119524
  B = 0.503486
  C = 0.002465
  D = 0.009992
  E = 1.252179
  F = 59.918513
}

FIT_PARAMS {
  LAMBDA = 0.550
  RHO = 0.075211
  K0 = 6.8702
  K1 = 0.3881
  K2 = 29.0824
}

FIT_PARAMS {
  LAMBDA = 0.750
  RHO = 0.453327
  K0 = 40.9686
  K1 = -1.6822
  K2 = 93.1120
}

```

For more information, consult:

- *Polarimetric Remote Sensing in the Visible to Near Infrared*, J. Shell, Ph.D. Thesis, Center for Imaging Science , Rochester Institute and Technology, 2005. <http://www.dirsig.org/docs/shell.pdf>

Shell Target BRDF

The Shell Target BRDF can compute polarized reflectances for target (man-made) materials. It is described in James Shell's PhD thesis.

A parameter file holds model fit data at measured wavelengths. A DIRSIG3 style emissivity file (ems) is used to help interpolate and extrapolate for other wavelengths. The interpolation method parameter dictates how DIRSIG spectrally interpolates the ShellTarget BRDF based on the fact that the BRDF parameters are usually only specified at a handful of wavelengths (i.e 0.325, 0.6328, 1.06 etc..) while the spectral emissivity is specified at a much higher spectral resolution. Interpolation method 0 ignores the high spectral fidelity emissivity curve, and simply utilizes the BRDF parameter fit data and linearly interpolates between the reference wavelengths. Interpolation method 1 mimics the NEF database v10 handling of BRDF spectral interpolation, utilizing the higher spectral resolution emissivity curve to adjust the diffuse portion of the BRDF such that the hemispherically integrated BRDF model matches the measured diffuse hemispherical reflectance curve.

The material database entry simply specifies the fit and emissivity files:

```

REFLECTANCE_PROP_NAME = ShellTarget
REFLECTANCE_PROP {
  BRDF_FIT_FILE = ./blackpaint.fit
  EMISSIVITY_FILE = ./blackpaint.ems
  INTERPOLATION_METHOD = 1
}

```

The BRDF fit file contains two or more "FIT_PARAMS" sections, which hold measurements at a known wavelength. The parameters are defined:

- "LAMBDA" is the wavelength in microns
- "N" is the complex index of refraction, real part
- "K" is the complex index of refraction, imaginary part
- "DHR" is the Directional Hemispherical Reflectance

The remaining sections of a "FIT_PARAM" entry define a microfacet orientation distribution, a shadowing function, and a volumetric term.

The "ORIENT_PROB" section indicates a Cauchy distribution function which is defined:

$$p_C(\theta_N) = \frac{B}{\cos(\theta_N)[\sigma^2 + \tan^2(\theta_N)]}$$

where B and σ are fit parameters, named "BIAS" and "SIGMA" in the fit file.

The "SHADOW_FUNCT" section indicates a Maxwell-Beard shadowing function which is defined:

$$S_{MB} = \frac{1 + \frac{\theta_N}{\Omega} e^{-1\beta/\tau}}{1 + \frac{\theta_N}{\Omega}}$$

where Ω and τ are fit parameters, named "OMEGA" and "TAU" in the fit file.

The "VOLUME_TERM" section indicates a Maxwell-Beard volumetric scattering component which is defined:

$$V_{MB} = \rho_D + \frac{2\rho_V}{\cos(\theta_i) + \cos(\theta_r)}$$

where ρ_D and ρ_V are fit parameters, named "RHO_D" and "RHO_V" in the fit file.

A sample fit file follows:

```

SHELL_TARGET = 1.0
FIT_PARAMS {
  LAMBDA = 0.352
  N = 1.449
  K = 0.2146
  DHR = 0.0464

  ORIENT_PROB_NAME = Cauchy
  ORIENT_PROB {
    BIAS = 0.0603
    SIGMA = 0.3553
  }

  SHADOW_FUNCT_NAME = Maxwell-Beard
  SHADOW_FUNCT {
    TAU = 2.17
    OMEGA = 1.47E+02
  }

  VOLUME_TERM_NAME = Maxwell-Beard
  VOLUME_TERM {
    RHO_D = -1.06E-04
    RHO_V = 5.29E-04
  }
}
FIT_PARAMS {
  LAMBDA = 0.632
  N = 1.405
  K = 0.2289
  DHR = 0.0402

  ORIENT_PROB_NAME = Cauchy
  ORIENT_PROB {
    BIAS = 0.0556
    SIGMA = 0.3331
  }

  SHADOW_FUNCT_NAME = Maxwell-Beard
  SHADOW_FUNCT {
    TAU = 1.717
    OMEGA = 1.19E+02
  }

  VOLUME_TERM_NAME = Maxwell-Beard
  VOLUME_TERM {
    RHO_D = -1.76E-04
    RHO_V = 5.43E-04
  }
}

```

For more information, consult:

- *Polarimetric Remote Sensing in the Visible to Near Infrared*, J. Shell, Ph.D. Thesis, Center for Imaging Science , Rochester Institute and Technology, 2005. <http://www.dirsig.org/docs/shell.pdf>

Ward BRDF

The Ward BRDF model has the advantage of being extremely simple. It is described in it's entirety directly in the material database:

```

REFLECTANCE_PROP_NAME = WardBRDF
REFLECTANCE_PROP {
  DS_WEIGHTS = 0.00 0.37
  XY_SIGMAS = 0.13 0.13
}

```

The XY_SIGMAS parameter values "represent the standard deviation of the surface slope in each of two

perpendicular directions" (Ward 92).

The two DS_WEIGHTS values represent the diffuse and specular weightings, respectively.

For more information, consult:

- Ward, G. J. 1992. *Measuring and modeling anisotropic reflection*. SIGGRAPH Comput. Graph. 26, 2 (Jul. 1992), 265-272.

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