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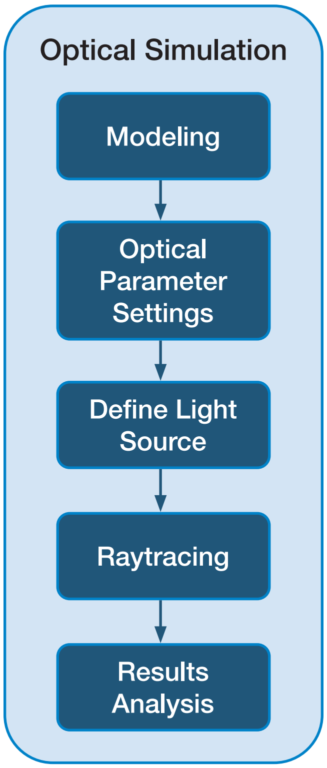
THE IMPORTANCE OF OPTICAL SIMULATION

Optical simulation and verification are essential tools for visualizing and validating design performance, playing a critical role in modern industries. Optical simulation focuses on designing and simulating optical systems, using physics and mathematics to analyze light behavior, including reflection, refraction, and diffraction. It enhances product efficiency and reliability, boosting performance and customer trust. Verification ensures models meet required standards, minimizing errors and recalls.



Optical simulation involves several key steps, including shape design and modeling, optical parameters (material and surface property settings), light source definition, ray tracing, and results analysis. If the results are unsatisfactory, the design can be iteratively modified. Among these steps, the settings for surface and material properties significantly impact the accuracy and outcomes of the simulation. This article will briefly explain several crucial optical parameters that play an essential role in simulation.

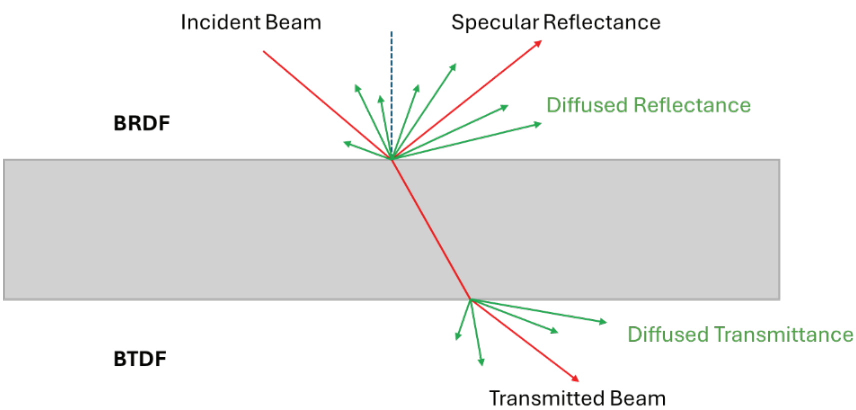
Refraction: Refraction is an optical phenomenon wherein the propagation direction of light changes as it passes from one medium into another due to differences in refractive indices between the two media. This behavior is described by Snell's law. Refraction significantly impacts light propagation within materials. High refractive index materials substantially alter the light path, producing pronounced optical effects. In practical applications, protective lenses are typically placed above sensors, making the refractive index of the lens a critical factor affecting the light path in optical simulations. The refractive index of polycarbonate (PC) material in the visible light spectrum typically ranges from 1.58 to 1.59, while at the 940 nm wavelength it is slightly lower, approximately 1.56 to 1.57.

Reflection: Reflection can be categorized into two types: specular reflection and diffuse reflection. Specular reflection follows the law of reflection, where the angle of incidence equals the angle of reflection. Typically, lenses without specific anti-reflective coatings have a normal reflectance of approximately 4 %. Diffuse reflection, on the other hand, occurs on rough surfaces, causing light to scatter in various directions randomly. In practical applications, specular reflection and diffuse reflection often coexist.

Absorption: When light passes through a medium, its energy gradually transforms into heat or other forms of energy, leading to a reduction in light intensity. The absorption rate typically varies with the wavelength used and is also influenced by the material's thickness. Absorption impacts optical simulations in multiple ways, especially in practical applications in which light travels back and forth between the sensor setup and the target object. For proximity sensors or ambient light sensors, PC material is commonly used as the lens. Typically, its absorption rate is less than 5 % in the visible light spectrum and does not exceed 10 % at 940 nm.

Wavelength: In optical simulations, both the light source and its wavelength are crucial factors that significantly impact the behavior of different materials. The wavelength of light determines how it interacts with materials at a microscopic level. Different materials respond uniquely to various wavelengths due to their intrinsic optical properties, such as refractive index and absorption coefficient, which vary across the spectrum. Moreover, the characteristics of the light source - such as its spectral distribution and intensity - also influence how light propagates through or reflects off surfaces. Proximity sensors typically use a 940 nm light source, with two common options being vertical-cavity surface-emitting lasers (VCSEL) and LEDs. LEDs typically have a wide light field, whereas VCSELs produce a much narrower light field.

Scattering: Scattering refers to the phenomenon in which the propagation direction of light changes upon encountering an inhomogeneous medium or small particle. Scattering is diverse and complex, primarily depending on the size of the scattering particles and the wavelength of light. Surface scattering is another significant phenomenon. This process can be described by the bidirectional scattering distribution function (BSDF), which relates to the angular distribution of an incident and scattered light. In optical simulation, the bidirectional scattering distribution function (BSDF) is a critical concept, describing the statistical properties of light scattering from a surface. BSDF comprises two components: the bidirectional reflectance distribution function (BRDF), which describes the behavior of light reflecting off a material surface, and the bidirectional transmittance distribution function (BTDF), which accounts for light scattering after transmitting through a material. Together, these functions provide a complete description of surface scattering.



The ABg BSDF model is a mathematical model used to simplify and approximate surface scattering behavior, and is particularly suitable for rough and complex materials. Renowned for its mathematical simplicity and accuracy in simulation, the ABg model is especially valuable in resource-constrained environments. It flexibly simulates surface optical properties, from specular reflection to fully diffuse scattering, accommodating a wide range of optical characteristics. The ABg BSDF model derives its name from its core parameters. Its formula can be simplified as follows:

$$BSDF = \frac{A}{B + \left|\beta - \beta_0\right|^g}$$

where:

- **A** is a constant representing the overall scattering intensity or the maximum value. It scales the BSDF to fit the desired intensity level
- **B** is an offset parameter. It affects the baseline of the BSDF value, determining the minimum scattering intensity when there is no directional change
- $\boldsymbol{\beta}$ and $\boldsymbol{\beta_0}$ represent the angles (or direction vectors) of the incident and ideal reflected / transmitted directions, respectively. The difference $|\beta\text{-}\beta_0|$ can be understood as the scattering angle
- $\boldsymbol{g}$ is an exponent parameter that controls the concentration or spread of the distribution. When g increases, the BSDF becomes more concentrated around $\beta\text{-}\beta_0$, indicating stronger directionality

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Parameter B primarily describes the impact of surface roughness on light scattering. As surface roughness increases, light scatters more diffusely; a larger B value results in a broader scattering distribution, while a smaller B value indicates more concentrated scattering, resembling specular reflection. The parameter g characterizes the directionality of light scattering. This parameter ranges from -1 to 1, directly influencing whether light scatters primarily in the forward or backward direction.

Range and Implications of the *g* Value:

- When $g = 0$, the scattering intensity is equal in all directions, representing an ideal Lambertian surface
- When $g > 0$, the scattering is predominantly forward, suitable for describing light-transmitting materials such as glass
- When $g < 0$, the scattering is mainly backward, as observed in some optical properties of partially opaque materials

The diagram below illustrates the simulation of different *g* values causing varying degrees of divergence. The left image represents $g = 2$, while the right shows $g = 0$. As observed, the reflected light increases as the *g* value becomes larger.