Chapter 6
Physical Optics

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ABSTRACT

Physical optics (PO) is one of the fundamental and powerful high-frequency theories for electromagnetic scattering and radiation. The total field of a source (antenna) which radiates in the presence of a perfectly conducting surface may be expressed as a superposition of the incident and the scattered fields. The current fields which exist everywhere are chosen in PO to denote the electric and magnetic fields of the source, i.e., they exist as if the scatterer was "absent"; this is unlike the geometrical optics (GO) incident field, which exists in the presence of the surface of the scatterer. The scattered fields in this case can be expressed in terms of the radiation integrals over the actual currents induced on the surface of the scatterer. These currents also radiate the scattered fields in the absence of the scatterer. This chapter shows the fundamental PO formulation and calculated results, and some topics which improve the conventional PO to the extended PO such as "physical theory of diffraction (PTD)" and "PO with transition current (PTD-TC)".

PHYSICAL OPTICS

Physical optics (PO) is one of the fundamental electromagnetic high-frequency theories for scattering and radiation problem. The total field of a source (such as an antenna) which radiates in the presence of a perfectly conducting surface may be expressed as a superposition of the incident field ($\boldsymbol{E}^i$, $\boldsymbol{H}^i$) and the field ($\boldsymbol{E}^s$, $\boldsymbol{H}^s$) which is scattered by the surface. The current fields are chosen in PO to denote the electric and magnetic fields of the source which exist everywhere, i.e., they exist as if the scatterer was "absent"; this is unlike the geometrical optics (GO) incident field, which exists in the presence of the surface of the scatterer. The scattered fields in this case can be expressed in terms of the radiation integrals over the actual currents induced on the surface of the scatterer. These currents also radiate the scattered

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fields in the absence of the scatterer, i.e., these currents are now viewed as equivalent sources, which are impressed over the mathematical boundary but with the perfecting conducting scatterer removed.

In the conventional PO method, the radiation integral for the scattered field is calculated by employing a GO approximation for the currents induced on the surface, which is assumed to be an electrically large plane; hence, the PO method is also a high-frequency method. In this chapter, the following are illustrated: the fundamental PO formulation and calculated results, and some topics which improve the conventional PO to the extended PO such as physical theory of diffraction (PTD) (Ufimtsev, 1971) and PO with transition current (PTD-TC) considering transition currents (Kobayashi, 1999). The PO method described here is the same concept as Kirchhoff's integration derived from the Huygens' principle.

Both the electromagnetic radiation and scattering which re-radiates electromagnetic waves around the scatterer from the induced currents are considered as a secondary source on the surface which is illuminated by incident waves. The PO is a typical high-frequency technology, and is a powerful calculation method with high accuracy of approximation if the size of scattering object is sufficiently large compared to the wavelength. There are two main features of PO from a practical point of view. First, there is a degree of freedom in how to express the electromagnetic current, and second, the scatterer surface which induces currents can be subdivided and calculated. As described later, the former can individually treat transition electromagnetic currents at discontinuities such as wedge, and the latter indicates that it can be divided into patches even if the target model has a complicated shape. It is well known that PO gives a finite value with a certain correctness near the focal point and focal line, and that the radiation integration includes a diffraction effect. In the general PO method, as mentioned above, the equivalent electromagnetic current of the radiation integral is obtained by the GO method. Since GO is a fundamental high-frequency theory that treats waves as ray, PO is also a high-frequency theory, so the electromagnetic current is zero in the shadow area of the scattering object. The electromagnetic current distribution in the transition region is also different from the actual one, and this is a reason that limits the application range of PO.

By analyzing from the viewpoint of the integral equation, it can be seen that the solution of PO evaluated by GO currents in the illuminated region is the result of ignoring the higher-order transition electromagnetic current term, and the contribution of the shadow region is canceled by the incident field. The general approach for determining the surface electromagnetic current using an integral equation is a matrix calculation. This method is not only time consuming but may also produce an incorrect result when the size of the scatterer is larger than the wavelength. Because of this reason, several attempts have been proposed to remove the aforementioned limitations based on PO, such as PTD and PTD-TC. As mentioned above, another feature of PO is the degree of freedom with respect to the segmentation area. A mathematical expression of the scatterer surface shape is required to perform the PO radiation integral analytically. The simplest shape is a flat plate, and the integration is evaluated assuming that the electromagnetic current flows on an infinite flat plate. Complicated and electrically large shaped objects are calculated by dividing them with a large number of flat plates, and numerical integration is performed when the shape is expressed by mathematical equations or data. In order to allow readers to have a detailed understanding on PO and PTD, the historical background of PO is first illustrated in this chapter. This is then followed by the explanation of the scattering caused by rotating curved surfaces and smooth convex flat plates.

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