Visualization of Physical Optics for Interpretation of High Frequency Phenomena

Tetsu Shijo, Takayoshi Itoh, Makoto Ando
Dept. of Electrical and Electronic Eng., Tokyo Institute of Technology, 2-12-1 O-okayama Meguro-ku Tokyo, 152-8552, Japan.

Abstract: High frequency diffraction is known to be a local phenomena and only parts of the scatterer contribute to the field such as the edge, corner and specular reflection point etc.. Many HF diffraction techniques such as GTD, UTD and PTD utilize these assumptions explicitly. Physical Optics (PO), on the other hand, expresses the diffraction in terms of the sum total of contributions from all part of scatterers, though the PO currents are locally defined. This paper presents the visualization of the scattering and diffraction phenomena by PO. It extracts only the important parts of current distribution for the given observation point. PO visualization demonstrates (1) local property of the high frequency scattering (2) defects associated with ray techniques (3) PO error factor, fictitious penetrating rays disturbing the geometrical shadow behind the opaque scatterer.

Visualization of scattering and diffraction phenomena

PO assumes a infinite plane at every point on the surface of the scatterer in lit region. Induced surface currents are approximated by Eq.(1).

\[ \hat{I}^\text{PO} = \hat{n} \times H' \quad (\hat{n}: \text{outer unit vector normal}, \ H': \text{incident field}) \quad (1) \]

Far scattered fields are given by the surface radiation integral of the PO currents over the illuminated surface of the scatterer. In the high frequency phenomena, according to the cancellation effect between adjacent currents, the electromagnetic wave from all the current distributions does not contribute to an observing point. The visualization extracts only the important parts of current distribution for given observation point, and explains the local property of the high frequency phenomena. The visualization method introduces the weight function named "EYE function" (Figure 1, Eq.2), at the point of interest on the surface. Brightness at some point is given by the surface radiation integral of the PO currents weighted with the EYE function with the center at that point. The above operation extracts only the important currents which survives after cancellation between adjacent currents due to rapid phase change in high frequency.

First, the radius of the EYE function \(a_0\) used the visualization is determined. Figure 3 shows the change in magnitude of the contribution from some stationary phase point on the scatterer, as the function of the radius of the EYE function. If the radius of an EYE function has the size exceeding the second Fresnel zone, brightness of the stationary point converges. The visualization in this paper uses the EYE function with the radius of 50\(\lambda\) which satisfies this condition for the distance of the source and the observer considered.

The visualization examples are given in Figure 4(a) for a rectangular plate and in Figure 5(a) for a dipole fed parabola. For the rectangular plate, the visualization results by PO and ray technique is compared in Figure 4(b) and (c), respectively. The inner bright point represents the reflection point, and four bright points on each side of the plate correspond to the edge diffraction. Very weak but still existing contributions are observed from the four corner points. Ray theory is reasonable in this situation.

Figure 5 shows the visualization for the parabola; the observer is far away 2500\(\lambda\) from the scatterer. Figures 5(b) and (c) show the pictures for different observation angle \(\theta\) when \(Zs=250\lambda\). For \(\theta = 0\) (deg), the
main contribution from the reflection point (the bright point inside) and edge diffraction from the rim of the
reflector which corresponds to the caustic phenomena on the axis; for $\theta = 30$ (deg), the reflection point and
two diffraction points appear. Above visualization clearly demonstrates the diffraction phenomena which
coincide with the prediction by Ray theories in diffraction (GTD etc.). Figure 5(d) shows the pictures when
the source is located on the focus. From the pictures, the important phenomena of caustic where all the
reflection from inner points add in phase (the focusing effect) are observed.

---

**Fig.3**: Relation between radius of EYE function and convergent validity of brightness

---

**Fig.4**: Visualization of scattering phenomena from rectangular plate illuminated by small dipole

---

**Fig.5**: Visualization of scattering phenomena from dipole fed parabola

---

**Visualization of fictitious penetrating rays**

As is well known, PO approximation is generally inaccurate in the shadow region. There are two error
factors; (i) the well known diffraction errors in the edge of the scatterer and (ii) existence of rays to disturb
the geometrical shadow behind the opaque scatterer in high frequency [2]. For correction of PO errors, most
works have been directed to correct the factor (i); PTD improves the factor (i) by introducing GTD
diffraction coefficients. Figure 6 shows radiation pattern of the corner reflector by PTD and the reference
solution by the method of moment (MoM). PTD is also inaccurate in the shadow region. It demonstrates the
error factor (ii). If the surface is not planar, penetrating rays are always generated in PO (PTD) and disturb
the shadowing effects, which is general and primitive requirement in high frequency. These rays could be the
leading error factors in PO (PTD) and were named as fictitious penetrating rays [2]. In this section, the
fictitious penetrating rays are visualized for interpretation.

In the shadow region, the visualization of the total fields is conducted. It consists of scattered field
from the PO currents and the direct incident wave, the latter should be canceled by the contribution from the
stationary phase point of the former. By expressing the incidence in terms of equivalent currents as well, the currents to be visualized is modified to those;

\[ I = \mathbf{n} \times \mathbf{H}' - M = E' \times \mathbf{n} \quad (\mathbf{n}: \text{outer unit vector normal, } (E', H'): \text{incident field}) \]  

(3)

The visualization is applied for the corner reflector in the 2-dimensional problem shown in Figure 7. The radius of the EYE function is 50 \( \lambda \). Figure 7 shows the generation of the fictitious penetrating rays at the corner, which causes the errors of PO in shadow region. Base upon the interpretation suggested by visualization, new method named PTD-AF was proposed which eliminate of the fictitious penetrating from PTD[3]. PTD-AF is accurate in all regions as is shown Figure 6.

Figure 8 shows the visualization of the fictitious penetrating rays generated from curved surface with different curvature; 0\( \lambda \) (corner), 5\( \lambda \), and 50\( \lambda \) (moderate curved surface). If curvature radius becomes large and a surface is approaching planar, the intensity of the fictitious penetrating rays decreases.

**Conclusion**

In this paper, we presented the visualization of the scattering and diffraction phenomena by PO, and demonstrated (1) local property of the high frequency scattering (2) defects associated with ray techniques (3) PO error factor, the fictitious penetrating rays.

In high frequency, calculation load of the conventional boundary value problems which solve induced currents on the scatterer becomes large. Although there are the induced currents all over the surface of the scatterer, the important contribution of the electromagnetic waves seen from the observing point is due to local part of the currents. For example, the reflection points and the diffraction points. The visualization extracts the important currents which contribute to the observing point and demonstrate the local property of the phenomena. The interpretation thus illustrated suggests the ways out of errors.

**REFERENCES**