Transverse fractal boundary conditions in a class of diffraction problem

I. Begleris, J. M. Christian, and G. S. McDonald

Materials & Physics Research Centre,
University of Salford, Greater Manchester M5 4WT, UK

KEYWORDS

diffractals, fractals, Fresnel diffraction, optical complexity, von Koch snowflake.

ABSTRACT

Diffraction plays a fundamental role in our understanding of propagation phenomena in essentially all wave-based systems, and it is perhaps at its most fascinating when the system under consideration incorporates some degree of fractality (where proportional levels of spatial structure persist over many decimal-orders of length-scale). For example, "diffractals" – proposed by Berry nearly a quarter-century ago – are plane waves scattered from a fractal phase object that have acquired multi-scale characteristics in their statistical properties [Berry, J. Phys. A: Math. Gen. vol. 12, 781 (1979)].

Here, we report on our recent theoretical study of near-field diffraction of light waves from hard-edged fractal amplitude objects. Particular emphasis is placed on the classic von Koch snowflake, both apertures and stops. Related work by other authors has addressed mainly far-field patterns [Uozumi *et al.*, J. Mod. Opt. vol. 38, 1335 (1991)]. Here, analysis is facilitated by reformulating the traditional Huygens-Fresnel diffraction integral as a circulation around the aperture edge [Huang *et al.*, J. Opt. Soc. Am. A vol. 23, 2768 (2006)]. Key results will be presented for several stages of snowflake development, where each new stage introduces an additional layer of substructure into the boundary of the aperturing element. Our research in this area has developed new and very general mathematical tools for predicting how waves interact with complex structures. While an optical context has been considered for definiteness, the phenomena and patterns involved are universal and we fully expect our results to find wider applicability in other branches of physical and engineering sciences.

Commentary

The spreading-out of waves as they pass through an aperture – diffraction – is a fundamental process that pervades the physical universe and appears in a diverse range of contexts. The diffraction of sound waves in enclosed spaces has implications for the design of concert venues. The interaction of ocean waves with coastal structures can often be a key consideration in marine engineering projects. And in optics, understanding how light waves from a laser diffract at apertures is crucial to the design of a whole range of modern technologies – such knowledge underpins all the photonic devices that are driving today's digital revolution "behind the scenes." Diffraction-related phenomena tend to be universal and largely independent of system specifics. They provide the currency in an interdisciplinary bazaar where scientists, engineers, and mathematicians from a broad spectrum of backgrounds can come together to share information and expertise on ideas of common interest and practical importance.