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Eigenmodes of Next-Generation Unstable Cavity Lasers: Kaleidoscopes, Snowflakes, Pentaflakes, and Fractal Dimension

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We will report on our latest research into fractal lasers (linear systems which involve geometrically-unstable resonators with inherent magnification) [1], introducing two new classes of transverse cavity configuration. These devices are of fundamental interest as table-top generators of tunable fractal light that can be used in a wide range of applications – from optical probes (e.g., increased sensitivity in surface roughness measurements) to secure information encoding/transmission to medical imaging. Moreover, we expect them to play a pivotal role in new Nature-inspired optical architectures and devices (e.g., writing fractal structures into new materials).

Attention will be paid not only to the classic kaleidoscope geometries [2], but also to recently-proposed designs which incorporate a feedback mirror whose outer boundary corresponds to increasing iterations of the von Koch snowflake [3] (a six-fold-symmetric iterated function system involving self-similar sequences of equilateral triangles – see Fig. 1) and its five-fold-symmetric counterpart, the von Koch pentaflake (constructed in a similar way to the more traditional snowflake, but using isosceles triangles). All three systems can be modelled using a two-dimensional virtual source (2D-VS) method [4], which unfolds the unstable empty cavity into an equivalent sequence of virtual apertures of increasing size [5]. A selection of mode patterns and eigenvalue spectra will be presented, and convergence issues considered in some detail.

![Fig. 1](Image)

A key issue to be addressed in detail is the fractal dimension of unstable-resonator modes for cavities with arbitrary parameters (i.e., equivalent Fresnel number \(N_{\text{eq}}\) and round-trip magnification \(M\)). Previously, Berry has made similar considerations but only for the lowest-loss modes of kaleidoscope cavities, and in the limit \(N_{\text{eq}} \to \infty\) (where asymptotic approximations may be deployed) [6]. We will conclude with a summary of results from the first detailed exploration of fractal dimension in kaleidoscope resonators. Specialist software [7] has been deployed in parallel with our suite of 2D-VS codes to investigate potential anisotropy in the dimension using various different measures: power spectrum, roughness-length, rescaled range, and variogram. One-dimensional cross-sections through the lowest-loss (and several higher-order) mode patterns are computed, and direct comparisons with a strip resonator for the same cavity parameters [8] uncover some intriguing results.

References