DIRECTIVE EMISSION FROM PHOTONIC QUASICRYSTALS 
WITH 12-FOLD SYMMETRY

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Abstract: This paper deals with the study of the electromagnetic radiation from electric line sources embedded in two-dimensional photonic “quasicrystal” slabs made of dielectric rods arranged according to a 12-fold symmetric aperiodic tiling. Preliminary numerical results, based on a rigorous full-wave method, seem to indicate significant improvements, in terms of sidelobe levels, as compared to previous studies (restricted to 5-fold-symmetric Penrose-type geometries).

INTRODUCTION AND BACKGROUND
During the last two decades, there has been a growing interest in the study of the physical properties and applications of aperiodically-ordered structures, related to the concept of “quasicrystals” in solid-state physics, in many fields of science and technology (see [1] for a recent review on the subject, and [2] for an up-to-date bibliography database). In electromagnetic (EM) engineering, use of photonic quasicrystals (PQCs) has been proposed in several applications, involving lasers, negative refraction and superlensing, high-impedance substrates etc. (see [3-6], and the references therein, for a sparse sampling). In [7], we presented a comparative study of two-dimensional (2-D) QPCs made of dielectric rods arranged according to selected aperiodic tiling geometries, featuring different types and degrees of order and symmetry. In particular, we studied in detail the radiation from a line source embedded in a PQC slab with Penrose-type (5-fold symmetry) lattice. Results showed the possibility of achieving moderate directivity at three frequencies located nearby the (main and secondary) bandgaps, with the lowest frequency smaller (~68%) than the (single) value observed for a periodic photonic crystal slab with comparable size and filling factor. However, the sidelobe level (~5dB) was still rather high.

In this paper, we show that significant improvements can be obtained by using PQCs with 12-fold symmetry, similar to those considered in [6] for negative refraction and superlensing applications.

DIRECTIVE EMISSION FROM PQCs WITH 12-FOLD SYMMETRY
Geometry and Parameters. As in [7], we consider a 2-D (z-invariant) geometry (see Fig. 1) involving a slab of 435 dielectric rods located at the vertexes of a 12-fold-symmetric aperiodic tiling (see the inset in Fig. 1) generated combining square and equilateral triangles according to the Stampfli rules [6,8]. The total size of the slab is \(107a \times 4.3a\), with \(a\) being the period of an equivalent periodic crystal slab having the same total size and filling factor. The rods have radius \(r = 0.15a\) and relative permittivity \(\varepsilon_r = 12\). A time-harmonic electric line source is located at
\((x = 0, y = -0.52a)\), with a slight vertical displacement from the symmetry center of the tiling (at \(x = y = 0\)), so as to avoid the placement inside a dielectric rod.

**Preliminary Results.** Figure 2 shows the EM response of the PQC of interest computed via a well-established full-wave numerical technique based on a multipolar Fourier-Bessel expansion [9]. Specifically, Fig. 2(a) shows the normalized radiativity (cf. [7, Eq. (2)]) from a 257-rod square-shaped PQC slab as a function of the normalized frequency \(a/\lambda_0\) (with \(\lambda_0\) denoting the free-space wavelength), from which at least three bandgap regions can readily be identified as pronounced dips. Figure 2(b) shows the normalized radiation patterns in the top halfspace, for a line source embedded in the 435-rod PQC slab shown in Fig. 1, at three representative frequencies \((a/\lambda_0 = 0.220, 0.292, 0.678)\) for which some moderate-to-high directive behavior is achieved. It is observed that the two lowest operational frequencies turn out to be smaller than the lowest one in [7]. Moreover, while the sidelobe level at the lowest frequency \((a/\lambda_0 = 0.220)\) is comparable with those in [7], it is considerably lower (~10dB) at the other two frequencies \((a/\lambda_0 = 0.292, 0.678)\).

**CONCLUSIONS AND PERSPECTIVES**

We presented a study of directive emission from line source embedded in PQC slabs with 12-fold symmetry. Preliminary results turn out to be significantly better, in terms of sidelobe level, than those presented in [7] for the Penrose (5-fold symmetry) case. It should be noticed that the PQC slab in [7] was randomly extracted from the Penrose tiling, whereas the QPC slab here was extracted from the 12-fold-symmetric tiling preserving the (local) center of symmetry. Moreover, we cannot rule out the possibility that the improvement stems from a better matched choice of the slab size and/or filling factor. Accordingly, current and future investigations are aimed at better understanding the role of local vs. global symmetry, as well as the slab geometrical parameters, in the directive emission properties. Preliminary results, for 12-fold-symmetric PQC, seem to indicate a general degradation of the directivity when the line source is horizontally displaced from the \(x = 0\) symmetry axis. On the other hand, vertical displacements along the \(y\)-axis seem to yield, in certain cases, lower sidelobe levels. Similar parametric studies are being carried out for other (Penrose, 8-fold) PQC geometries. Also of interest is the development of leaky-wave-based analytic parameterizations of the radiated field.

**REFERENCES**


[2] http://www.quasi.iastate.edu/bib.html, maintained by the Quasicrystal Research Group at Iowa State University, IA, USA.


Figure 1 – Problem geometry (explained in the text).

Figure 2 – Electromagnetic response. (a) Normalized radiativity, as a function of normalized frequency, for a 257-rod square-shaped PQC slab. (b) Radiation patterns from a line source (at $x=0$, $y=-0.52a$) embedded in the 435-rod PQC slab shown in Fig. 1, at three representative frequencies (marked as arrows in (a)). Solid curve: $a/\lambda_0=0.220$; dashed curve: $a/\lambda_0=0.292$; dotted curve: $a/\lambda_0=0.678$. 