

Multiphysics Origami: Achieving Tunable Frequency Selective Surfaces from Origami Principles

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Abstract

Frequency selective surfaces (FSS) are periodic structures used to filter electromagnetic waves within a range of frequencies. These structures are not able to change or adapt their filter frequency range, which limits their application significantly. To address this problem, we develop a tunable FSS using the Miura-Ori pattern as a substrate for the periodic structures (conductor lines). We choose the Miura-Ori for several reasons: it is a developable pattern, it has a convenient manufacturing process, it has a single degree of freedom, which allows simple actuation (see Figure 1). Furthermore, this pattern has a negative Poisson's ratio, so it adjusts the distance between conductor lines in both Cartesian directions (x and y in Figure 1) as we change the effective length of the conductors. Another advantage of combining the Miura-Ori with FSS structures is that we can take advantage of the Miura-Ori geometry to stack multiple layers of the pattern without using another structure as a spacer to produce a response with a broader bandwidth. The stacking also adds new intrinsic parameters that allow more flexibility in the FSS design.

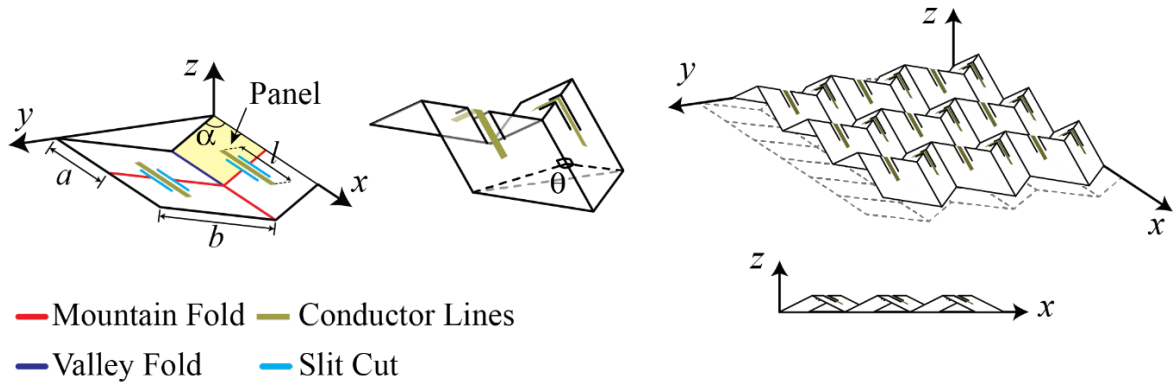


Figure 1: FSS Miura-Ori.

In this paper, we study Miura-Ori FSS with a single layer (Figure 1) and with distinct stacking configurations of the Miura-Ori layers (Figure 2). We also associate the FSS design parameters with the Miura-Ori intrinsic geometry so that we can efficiently design the tunable FSS structure. We relate panel lengths a and b of the Miura-Ori with a conductor length l that will result in the resonant frequency and the bandwidth of the tunable structure. To design the structures, we simulate the proposed Miura-Ori FSS using the Ansoft HFSS software. We opt

to take advantage of the periodicity of the structure and save computational time and resources; thus, we simulate the use of master-slave boundary conditions with Floquet port excitation for a unit cell. For verification of the simulated results, we fabricate and test prototyped models (Figure 3). For each structure layer, we fabricate the prototype from cellulose paper pre-creased with the Miura-Ori pattern, ink-jet print the dipole elements, fold the resulting 2D structure, and test its filtering capabilities at different folding angles. For the experimental test, we place the prototype between two horn antennas in the same line-of-sight and use 3D printed frames to guarantee that the prototype will retain the desired folding angle.

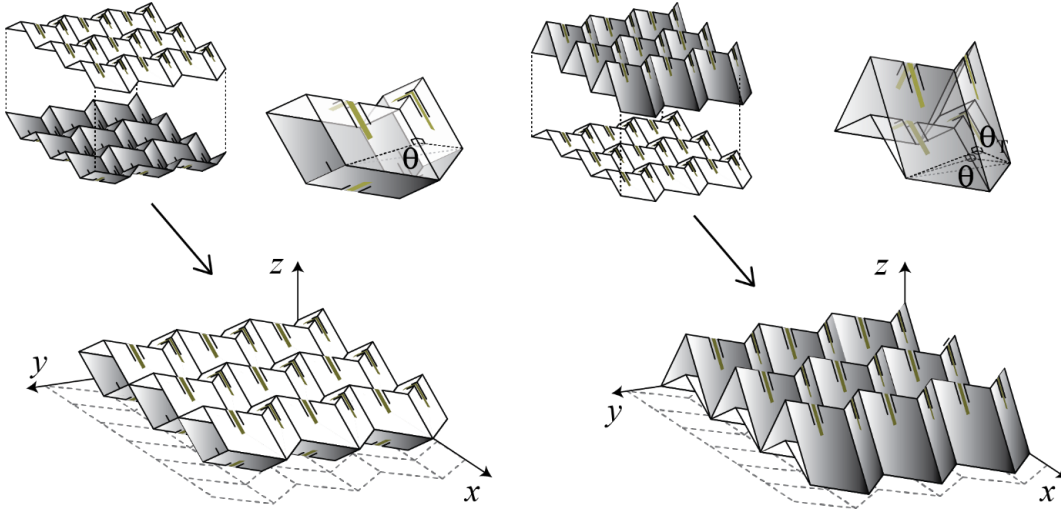


Figure 2: Multi-layer stacking of the FSS Miura-Ori.

From both numerical and experimental tests for a single Miura-Ori FSS, we observe that as we increase the Miura-Ori folding angle θ , we also increase the effective length of the conductor lines into the xy plane, which results in a shift in the resonant frequency, but only a slight change in the bandwidth. These observations reflect the tunability that we aimed to observe from this combination. In addition, we observe that, unlike conventional FSS composed of dipole elements, the Miura-Ori FSS has low sensitivity to the angle of incidence of the wave. The designs with multilayers of the Miura-Ori FSS exhibit similar shifts in the resonant frequency as we change the folding angle, but it filters a larger range of frequencies; that is, the stacked design has a broader bandwidth, which is a desired property in some applications. In summary, this work opens new avenues for programmable and multifunctional electromagnetic structures, and may enable researchers to find other suitable origami patterns for the design of tunable electromagnetic structures (different FSS and antennas).

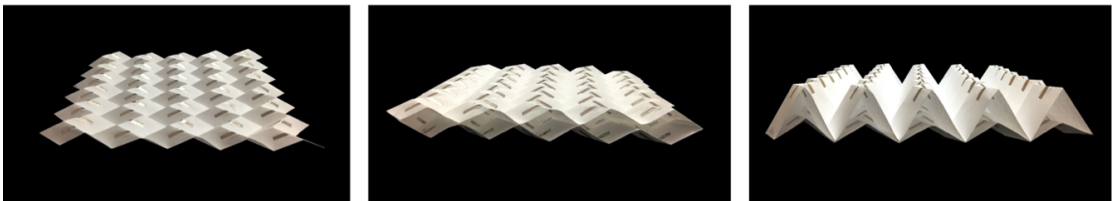


Figure 3: Prototyping of a single Miura-Ori FSS layer and the two-layer configurations.