Multihyperuniform shared aperture antenna arrays for multiband unidirectional emission applications

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***Abstract*—The multihyperuniform disordered distribution is an aperiodic distribution that was firstly identified on avian eye retina and is the reason behind their wideband and highly directive vision attributes. In particular, five different photoreceptor species are arranged in a disordered manner following a hyperuniform distribution which provides low side lobe levels and highly directive radiation patterns, while the overall photoreceptor distribution is hyperuniform as well, hence the term multihyperuniformity. Inspired by this, we are applying the concept in the field of shared-aperture antenna array design and to prove the concept, design a penta-band shared-aperture antenna array of circular patches operating in microwave frequencies. The proposed antenna array has low side levels over the whole frequency bandwidth and provides high peak realized gain values at the patches' resonant frequencies.**

I. INTRODUCTION

The concept of shared aperture antenna arrays has been of major importance to the antennas and propagation society for the past years as a viable all-in-one solution, mostly for base station antenna array applications. Furthermore, due to the steep evolution of the communication protocols over the past years, base station antennas need to be able to operate at increasingly higher frequencies, while at the same time, the previous generation protocols' allocated bands will still be used for various applications. Thus, the designed antenna arrays will need to simultaneously cover wide bands of the radio spectrum to accommodate the aforementioned need, while saving installation space and cost. Shared aperture antenna arrays for multiband operation have been mainly designed by employing periodic subarray distributions which are stacked together to form the overall array. This approach is limited due to the non-overlapping condition that needs to be imposed between the elements of the subarrays which greatly decreases the design degrees of freedom.

There exist several already published designs of shared aperture antenna arrays that are made of two or three different subarray distributions all distributed over the same aperture area. Several examples include the 2×2 C-band array incorporated with a 4×4 X-band array of patches [1], the single element UHF-band antenna situated over a 4×4 S-band array [2], or the work of [3], where the authors place a 2×2 array of S-band elements under a single antenna element operating at L-band frequencies that is designed so as to be transparent at the operating frequencies of the high-band array underneath it. All of these designs can operate over two different frequency bandwidths. There also exist a few designs that can operate over three distinct frequency bandwidths with some examples including the 4×6 S-band array placed under a 2×3 L-band array, which are both placed under a single UHF-band antenna element [4], as well as the work that can be found in [5], where the authors have meticulously placed a 2×2 X-band array, a 4×4 Ku-band array and 4×4 Ka-band array over the same aperture area without any element overlaps.

For the works that are presented here, as well as for other similar work in the literature, the periodic distribution of elements is employed where either all elements reside over the same aperture area, or each subarray is placed over other subarrays that make up the shared aperture antenna array. In the former, the choice of elements and their operating frequencies is rather limited, since any possible element overlaps needs to be avoided. In the latter case, complex design procedures are employed in order to make the elements that reside over other subarrays electromagnetically transparent. In either of the two cases, the design degrees of freedom is limited and the designs cannot be generalized in order to design shared aperture antenna arrays with desired operating frequencies and aperture area sizes.

II. SHARED-APERTURE ANTENNA ARRAYS WITH MULTIHYPERUNIFORM DISORDER

Antenna arrays with hyperuniform element distribution are shown to provide low side lobe level values over a wide range of frequencies and beam-steering angles [6]. This type of aperiodic array distribution is a sparse one which lies between a crystal and a random distribution. Specifically, in reciprocal space, there exists a circular area of low emission that surrounds the main lobe, as in a periodic array and outside this region the side lobes are kept at a low level as in a random distribution. Furthermore, the amount of order/disorder in the distribution can be controlled providing robust solutions to the wideband antenna array packing problem according to each problem at hand. These systems are identified from their structure factor behaviour, which is a function that is proportional to the scattered intensity of radiation from a system of points.

It has been found out that the photoreceptor distribution on avian eye retina is made up of 5 different photoreceptor patterns which are hyperuniformly distributed, while the overall photoreceptor distribution is hyperuniform disordered as well, hence the term multihyperuniform disorder. Inspired by this work and the previously published work on hyperuniform disordered antenna arrays, we are able to design multihyperuniform disordered shared-aperture antenna arrays that can operate at multiple operating frequencies, while maintaining low side lobe levels and guaranteeing no element overlaps.

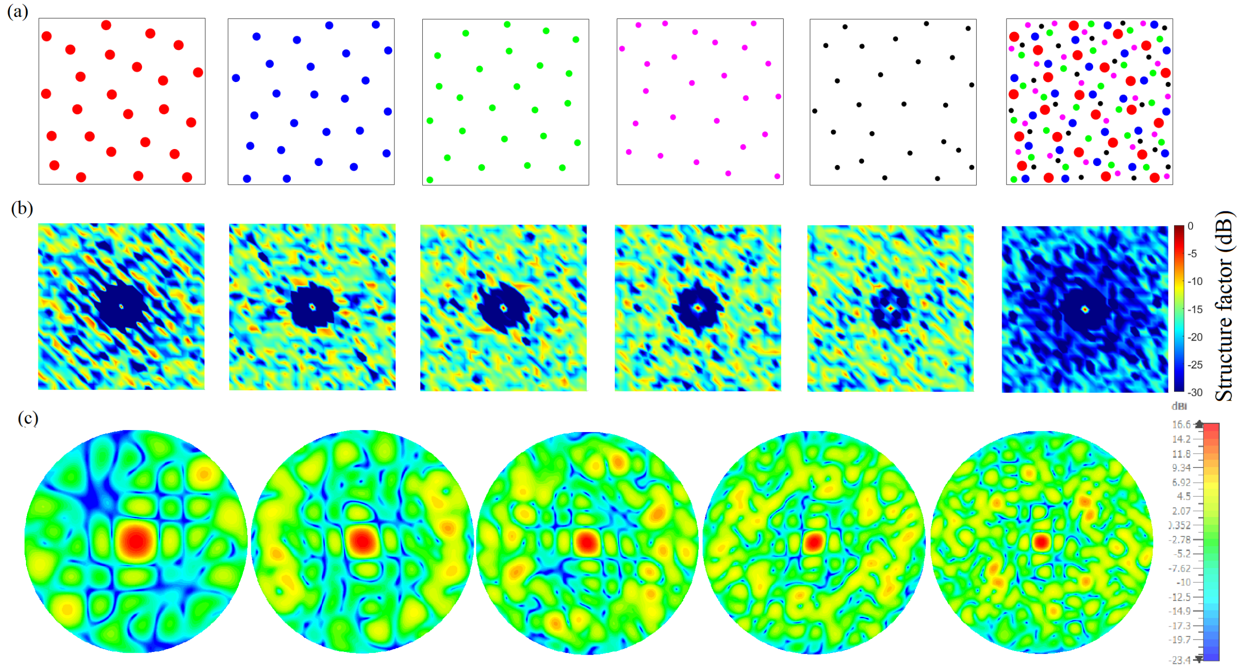

Fig. 1. The multihyperuniform array of circular patches made of 5 subarrays. (a) Array distributions, (b) corresponding structure factor plots, and (c) simulated radiation pattern (u, v) plots from left to right at 4, 5, 6, 7 and 8 GHz, respectively.

To prove the concept, we present a shared aperture antenna array made of 5 different subarrays of circular patches which resonate at 4, 5, 6, 7 and 8 GHz, respectively. The results of this process can be seen in Fig. 1, where the top panel shows each individual subarray distribution with the rightmost subfigure illustrating the overall distribution. The middle panel illustrates the corresponding structure factor behaviour of the subarrays and the overall array. The structure factor behaviour is characterized by a circular exclusion region that surrounds the main lobe, indicating hyperuniformity. The bottom panel from left to right illustrates the simulated far-field realized gain (u, v) plots of the multihyperuniform array of patches at their associated frequencies. The radiation pattern of the array adopts that of the structure factor maintaining low side lobe levels and a circular exclusion region surrounding the main lobe of radiation.

III. CONCLUSION

We have presented how the idea of multihyperuniform disorder can be employed for multi-band shared-aperture antenna arrays comprised of multiple different subarrays. Due to the sparsity of the hyperuniform disordered arrays that comprise the overall array, we are able to efficiently distribute more than three subarrays resonating at different operating frequencies. This approach increases the design degrees of freedom for the design of multi-band shared-aperture antenna arrays and warrants a novel and robust solution to the shared aperture antenna array packing problem. To the authors' knowledge there does not exist any multi-band arrays that can operate over more than three frequency bands, due to the periodic arrangement that has been employed in the past.

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