OAM MODE QUALITY COMPARISONS FOR DISCRETE EM RADIATING SOURCES

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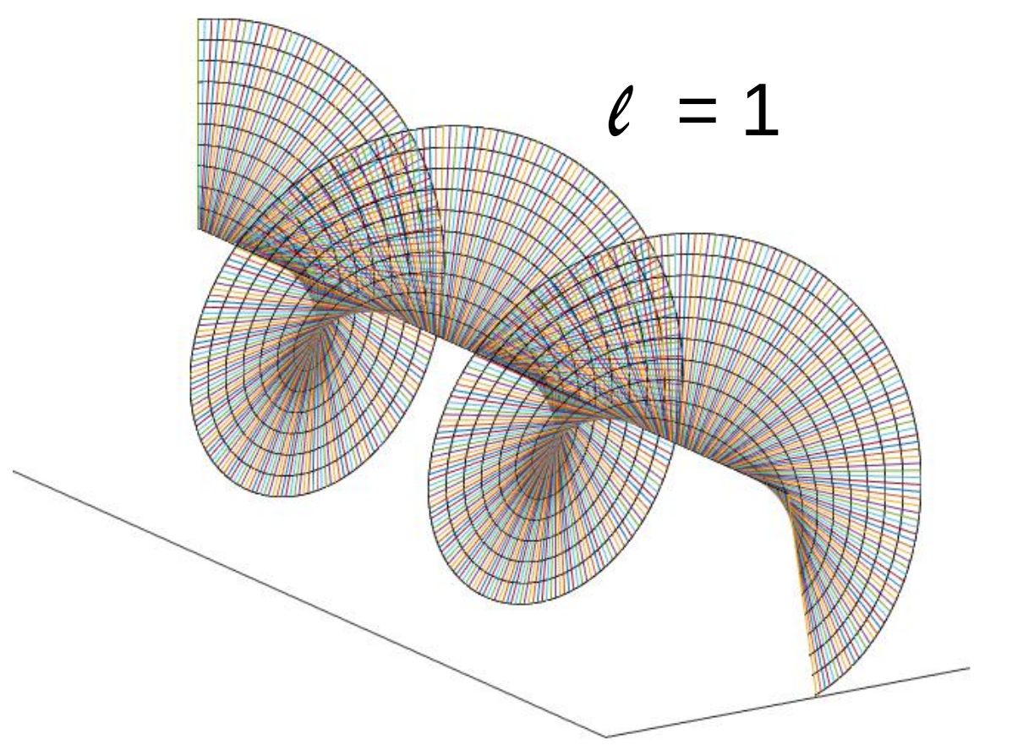
OAM EM WAVES

- Electromagnetic waves carrying the orbital angular momentum (OAM)
- Phase of the wave is twisted around the axis of propagation. The OAM wave is represented in the form of:

$$A(\mathbf{r})e^{j\psi} = A(\mathbf{r})e^{jl\varphi}$$

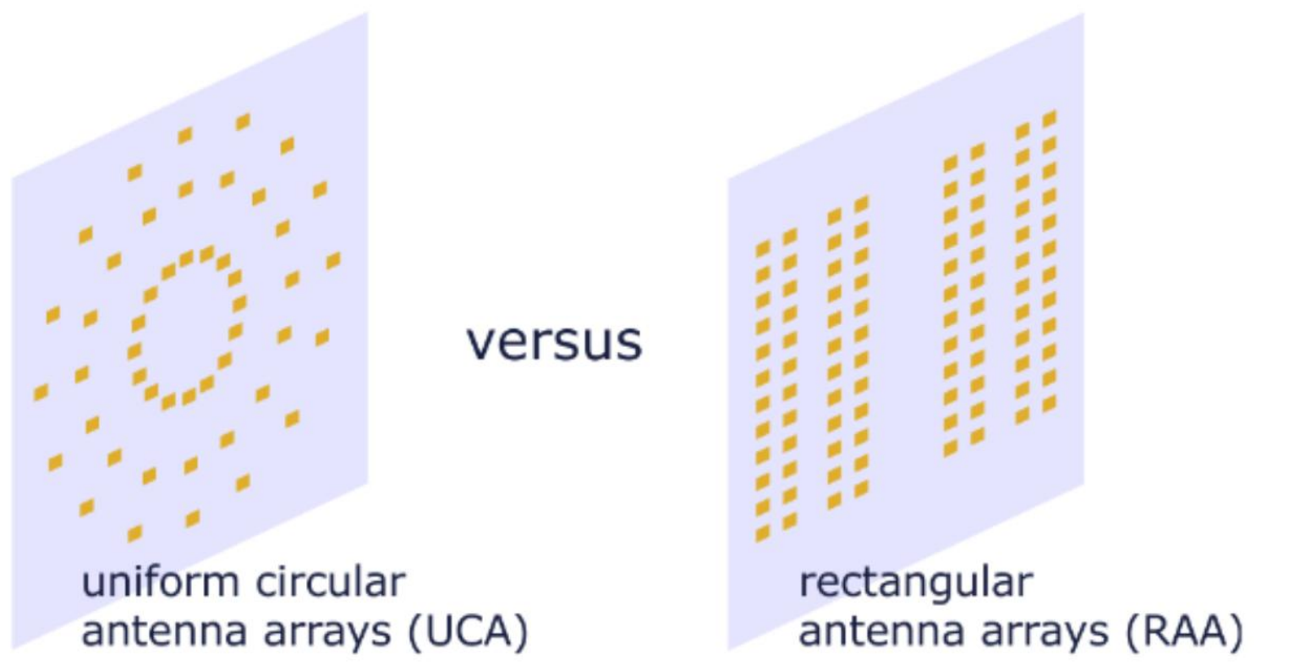
Where *A(r)* is the amplitude, *Ψ* = *ℓφ* is the phase of OAM EM wave and *ℓ* is OAM mode of the wave.



- Currently being considered for use in optical wireless communications, as well as wireless communications at terahertz and millimeter wave frequencies [1], [2].

PROBLEM

- Partial radiating apertures and discrete OAM wave sources: **OAM mode quality versus cost and complexity**
- The apertures radiating with their entire surfaces, often used in the optical domain, produce very high quality OAM EM waves. However, partial radiating apertures and discrete OAM wave sources, considered here, facilitate OAM source reconfiguration as well as multiplexing of different OAM modes trough a single aperture.



- At terahertz and millimeter wave frequencies, powering and phasing of discrete OAM EM wave sources often becomes increasingly more complex and costly.
- It is of interest to use low-cost, low-profile, efficiently powered and phased antenna arrays consisting of a limited number of elements, while optimizing OAM mode quality.
- Uniform Circullar Arrays (UCA) are often used to produce the OAM EM waves at millimeter wave frequencies.
- Rectangular antenna arrays (RAA) could offer some additional flexibility to the designer, but the phase shifts are more complex, and optimization might be required to obtain similar mode quality.

THE METHOD AND THE CALCULATIONS

FIELD CALCULATION

Quasi-analytical method to model OAM mode-generating antenna arrays, starting from a short dipole antenna model, proposed in [3].

We modeled the electric field generated by a sub-array as:

$$\mathbf{E}_{sn}(\mathbf{r}_{sn}) = \frac{F_{sn}(\beta, l_e, w_e, \theta_{sn}, \varphi_{sn})}{F_{Hd}(\beta, l_{Hd}, \theta_{sn})}\mathbf{E}_{Hd,n}(\mathbf{r}_{sn})$$

$$\mathbf{E}_{Hd,n}(r_{sn},\theta_{sn},\varphi_{sn}) = -\frac{\beta^2 l_{Hd}}{4\pi} Z_0 I_n \frac{e^{-j\beta r_{sn}}}{j\beta r_{sn}} \sin\theta_{sn}\,\mathbf{i}_{\theta n}$$

$$\mathbf{H}_{Hd,n}(r_{sn},\theta_{sn},\varphi_{sn}) = -\frac{\beta^2 l_{Hd}}{4\pi} I_n \frac{e^{-j\beta r_{sn}}}{j\beta r_{sn}} \sin\theta_{sn}\,\mathbf{i}_{\varphi n}$$

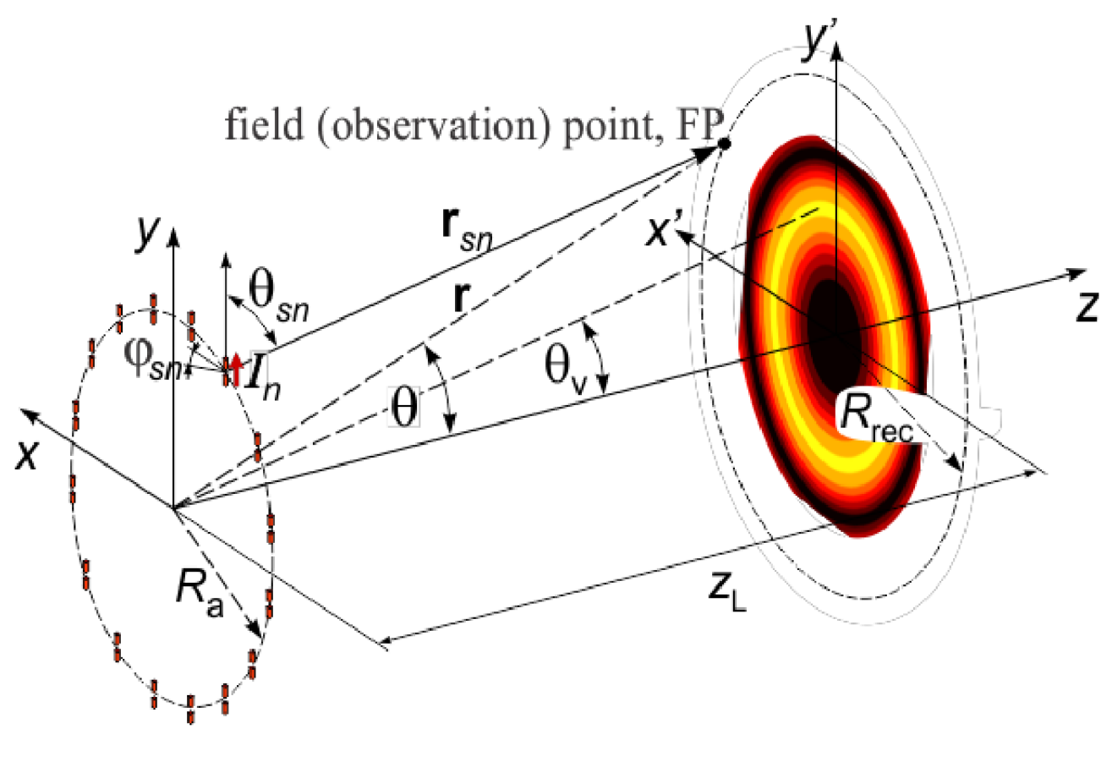


Illustration of OAM UCA array. The coordinate transformation between the global coordinate system (x, y, z) ,and the local spherical coordinate system of the n-th antenna (r_{sn}, θ_{sn}, φ_{sn}), took place to ensure the correctness of the calculations. Link distance is denoted as z_L. More detailed explanations of notation and calculations are available in [3].

Where the resulting OAM fields were obtained by summing the weighted dipole contributions:

$$\mathbf{E}(\mathbf{r}) = \sum_{n=1}^{N_a} \mathbf{E}_{sn}(\mathbf{r}_{sn}) = \sum_{n=1}^{N_a} K(\theta_{sn})\mathbf{E}_{Hd,n}(\mathbf{r}_{sn})$$

In the calculations, *y* polarization of EM wave is proposed.

CHARACTERISTICS OF OAM MODES

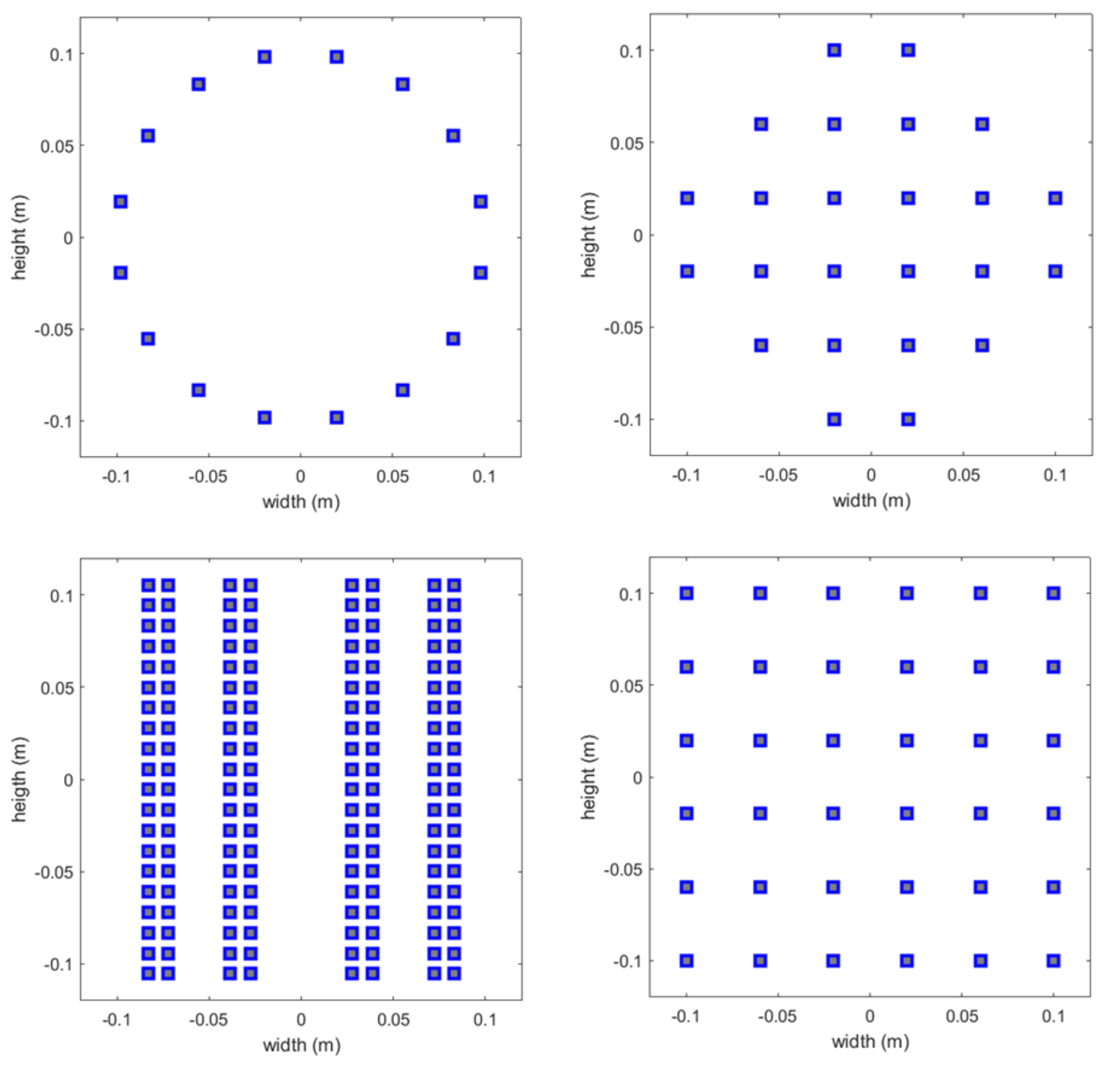
Analysis of characteristics of OAM waves is usually based on graphics representation of a wave profile, which is an indirect indicator for quality of OAM modes. Purity of OAM mode depends on the energy distribution of every mode, which can be seen from OAM spectrum. Spectrum values can be got from decomposition of modes with complex Fourier transform.

$$P(l, r_i) = \int_0^{2\pi} \frac{1}{2\pi}\psi(\phi, r_i)e^{-jl\phi}\,d\phi$$

RESULTS

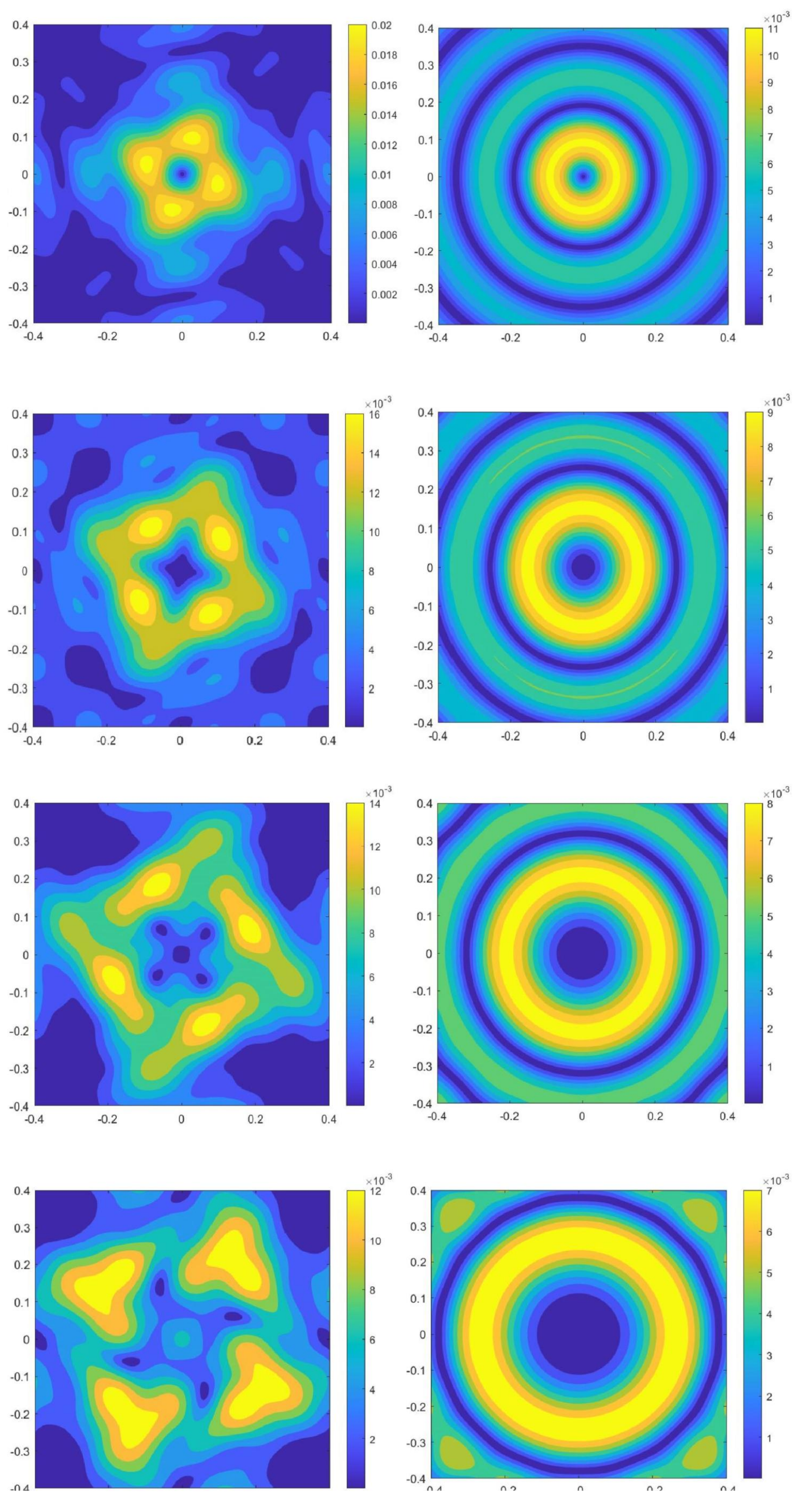
DIFFERENT ANTENNA ARRANGEMENTS

We compare the OAM mode quality of different antenna array arrangements at millimeter wave frequencies to define the prerequisites for the RAA for attaining high wireless data transfer performance. Here, we compare four different antenna arrangements. Wavelength of EM wave is *λ* = 5 mm. All antennas have similar dimensions, *D* = 40*λ*. Dipoles have length L_{Hd} = *λ*/25 and current I_{hd} = 1 mA. Spacing between dipoles is the same (*d* = *4* mm) for the UCA *(a)*, the disk-like *RAA (b)*, and the squared 6*6 RAA *(d).* For RAA *(c),* dipoles are packed in four strips with less spacing between them, *d* = *1.1* mm. We observe the field in the *z*-plane, at a distance *z* = 400*πλ* from the antennas.

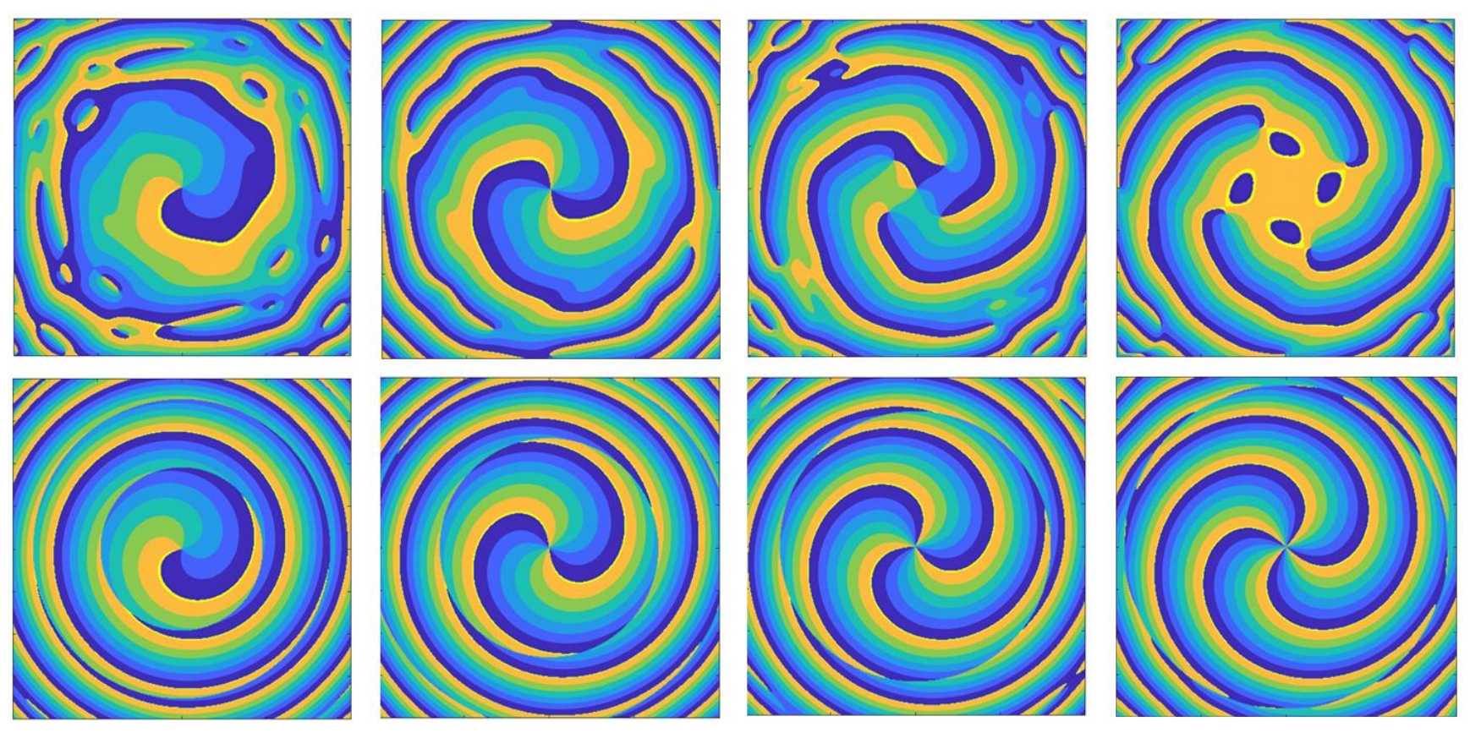


Antenna arrangements: (a) top left, UCA antenna with 16 dipoles; (b) top right, disk-like RAA antenna with 24 dipoles; (c) bottom left, RAA strips with 160 dipoles and (d) bottom right, RAA square with 36 dipoles.

INTENSITY AND PHASE OF THE FIELDS



Field intensity in the case of: (a) left, squared RAA antenna 1 to 4 OAM mode, (b) right, UCA antenna 1 to 4 OAM mode

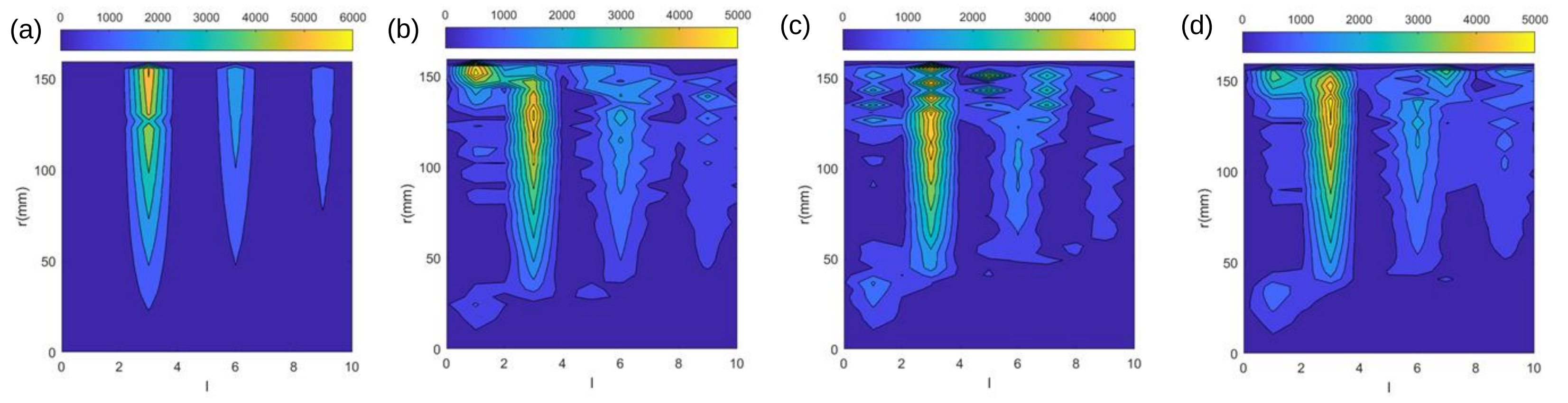


Phase formation in the case of: (a) top, squared RAA antenna 1 to 4 OAM mode, (b) bottom, UCA antenna 1 to 4 OAM mode

It can be seen that intensity of *Ey* component deviates from the typical ring shape obtained with the UCA source. Ratio of the maximal field intensities in the two cases (36 antenna RAA vs 16 antenna UCA) is 1.85. If we look at the phase formulation, we can see that the desired phase profile is formed, i.e. there is screw like phase. For the third and fourth OAM mode, there is a phase profile deformity in the center, but the phase is adequately formed in those regions, where the field intensity is the strongest. With more dipoles, both the intensity and the phase profiles improve, as expected. Disk-like RAA arrangement gives similar result as squared RAA with slightly lower EM field intensity.

OAM MODE QUALITY

Represented spectrum shows energy distribution for third OAM mode. It can be seen that the mode purity is the best for UCA array, but other antennas show good agreement with the UCA spectrum. For lower modes mode purity is improving for all antennas.



Spectrum showed for 3 OAM mode for: (a) UCA antenna with 16 dipoles; (b) RAA square with 36 dipoles; (c) RAA strips with 160 dipoles and (d) disk-like RAA antenna with 24 dipoles.

References

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Conclusion

Utilization of uniform circular antenna arrays (UCA) as discrete OAM EM wave sources has been successful in the millimeter wave frequency band. Uniform or non-uniform rectangular antenna arrays (RAA) provide additional flexibility to the designer and could benefit from the well-developed theory and implementation methods of conventional antenna arrays [4]. We compare the OAM mode quality of different antenna array arrangements at millimeter wave frequencies to define the prerequisites for the RAA for attaining high wireless data transfer performance.