Orbital Angular Momentum Mode Order Conversion with Helically Arranged Spherical Dielectric Resonator Arrays

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Vortex waves – Electromagnetic (EM) waves can carry spin angular momentum (SAM) when circularly polarized and orbital angular momentum (OAM) in the form of a vortex wave. The spin angular momentum, which is today well known in circularly polarized plane waves respective gaussian beams, has already been extensively studied and researched by many engineers in contrast to the OAM in vortex waves, which is a rather new topic in the area of RF engineering. OAM waves have an unlimited number of states *m* (i.e. the OAM mode order), which may define a new degree of freedom that allows to transmit multiple signals at the same frequency and at the same time and thus bears the potential for novel MIMO communication schemes.

Vortex wave excitation – There are many approaches to generate vortex waves like spiral phase plates (SPP) [1], holographic plates (HP) [2], metsaurfaces [3], (dual mode) elliptical patch antennas [4], and uniform circular patch antenna arrays [5]. The vortex waves are characterized by a doughnut-shaped radiation pattern with an associated helical phase distribution that changes linearly along the beam axis, having a phase singularity in the beam center where the phase is not defined but hidden by the zero in the radiation pattern. A new approach for vortex beam generation relies a structured resonant target [6] that consists of a helical arrangement of spherical dielectric resonators (DRs), which can interact with an impinging electromagnetic wave yielding vortex beams in reflection [7] and in transmission (each of which with a corresponding OAM mode order).

Illumination setup with helically structured target – The setup consists of a circular array of planar patch antennas, which is complemented by a particularly tailored lens [8] and directed towards a structured target consisting of helical arrangement of spherical DRs. The scattered signal from a DR depends on the size, on the relative permittivity ε_r, on the loss tangent ($\tan\delta$) and on the position of the DR. In case of a spherical DR, three groups of mode are supported (*TE*, *TM* and *HE*) when illuminated by an external plane wave.
Here in this paper, a rectangular patch antenna element is designed using the EM field simulator (FEKO), that is based on the Method of Moments (MoM). Without loss of generality the operating frequency is set to 10 GHz in order to ease subsequent experimental studies. The patch antenna is matched to 50 Ω. Moreover, the patch antenna is periodically arranged to form a circular patch array of 8 antenna elements aiming at the generation of a beam with e.g. OAM mode order $m = +1$. The distance between the adjacent antenna elements is $\lambda/2$ in order to reduce the side lobe level (SLL) and to increase the gain. Unfortunately, vortex beams are suffering from a considerable beam divergence, which can be counteracted with a correspondingly tailored lens [8]. The structured target is setup as a helically arrangement of 8 spherical DRs forming a helical array. This target displays 8 resonant scatterers that are individually excited with a corresponding "delay" given by the relative position of the DR with respect to the phase of an impinging wave from the circular patch array. Adjusting the height *h* between adjacent DRs (i.e. the separation distance along the helical axis), yields a phase delay for each DR element that may conform to the phase relations within a propagating vortex beam enabling OAM mode conversion due to OAM conservation. The DR with radius of 2.43 mm and a relative permittivity of 37 (ceramic), the spherical DR supports a HE_{11} mode at 10 GHz. The helically structured target is therefore apt to convert impinging vortex beams into reflected and transmitted beams with converted OAM mode orders as illustrated in Fig. 1.

OAM mode order conversion – Vortex beams with different OAM mode orders [namely 0 (a), +1 (b), –1 (c), +2 (d), and –2 (e), where the labels are set according to Fig. 1] are emitted from the lensed patch antenna array towards the structured target that is configured according to the OAM mode order –1. The OAM mode order emitted from the array antenna and the one inscribed into the helical target will be compensated yielding a reflected beam with converted OAM mode order and a transmitted beam that keeps the OAM mode order of the impinging beam. Hence, in the case (a) OAM mode order 0 is generated and converted to OAM mode order –1. In the case of (b) and (c) the OAM mode orders +1 and –1 are generated and converted into the OAM mode order 0 and –2, respectively. Similarly, the case (d) and (e) generate the OAM mode orders +2 and –2 and convert them into OAM mode orders +1 and –3. Please note that the phase pattern of the reflected (converted) beam for exciting mode order –2 is slightly distorted. This is due to the strong divergence of the doughnut-shaped OAM beams with mode orders ±2, which will lead to an increasing mask out of the helical target. Please note that the incident beam from the antenna and the transmitted beam have the same OAM mode order. In Fig. 1 we therefore display only the forward (transmitted) and backward (reflected) scattered beam, for visualization purposes as the incident beam is considerably stronger than the two scattered beams.

Conclusion – We have shown that the OAM mode orders of both, the incident (transmitted) and reflected vortex beam together with the OAM mode order of a helical target are interlinked by a simple «algebra» due to OAM conservation. This opens the field for novel target sensing/location schemes with inherent clutter suppression and enables even more complex applications such as e.g. chipless OAM-coded RFID tags [7].

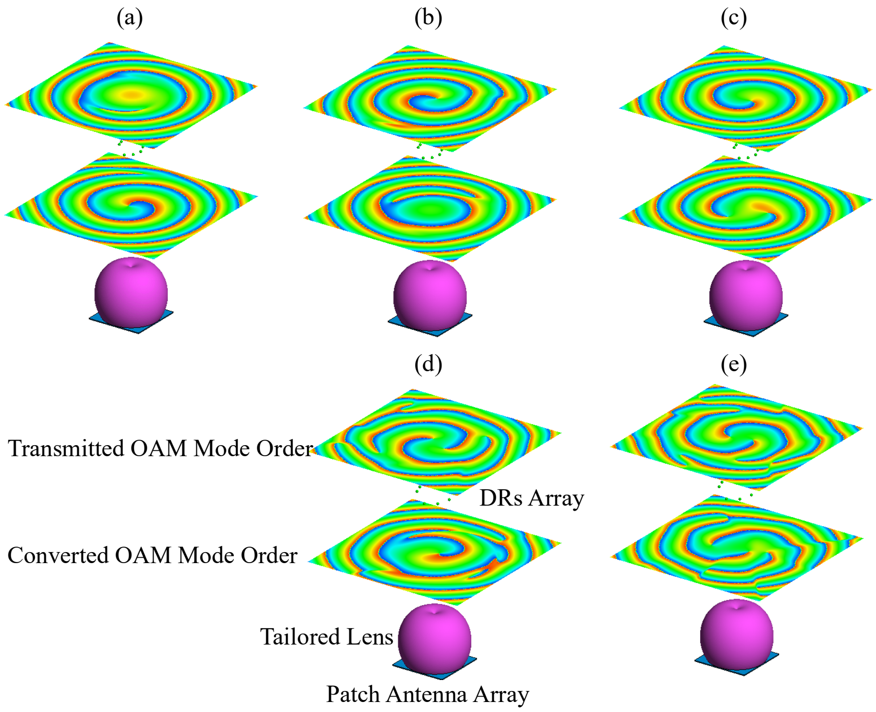

Fig.1: Different simulated scenarios for OAM mode conversion from the incident/transmitted OAM mode order to the reflected OAM mode order showing the phase distribution of the reflected and transmitted beams only: (a) 0 to –1; (b) +1 to 0; (c) –1 to –2; (d) +2 to +1; and (e) –2 to –3 (distorted). The helical target is configured according to the OAM mode order –1.

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