# Depolarizers for space applications consisting of spatially distributed meander structures with random orientation

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**Abstract**

Periodic single metallic meander structures exhibit extraordinary transmission in the visible frequency domain within a well-defined pass band that can be shifted by geometry variation. Additionally, they act as linear polarizers, induce phase retardation between s- and p-polarized light and convert the polarization of light due to plasmonic excitations. Those features combined with the advantages of plasmonic metamaterials in general, such as radiation stability, temperature independence and low weight make them perfect candidates for optical devices in space instruments. We use Mueller matrix calculations to show that an optical depolarizer can be realized with spatially distributed meander structures that are rotated arbitrarily. The investigated polarization scrambler can be flexibly designed to work anywhere in the visible wavelength range with a bandwidth of up to 100 THz. Furthermore, the depolarization effect relies on optical activity rather than scattering. With our preliminary design, we achieve depolarization rates larger than 60% for arbitrarily polarized, monochromatic or narrow-band light, respectively. One advantage of our concept is the flexibility to tune the polarization scrambler to a particular optical frequency or functionality. Circularly polarized light ($S = [1, 0, 0, \pm 1]$) for instance could be depolarized by 95% at 600 THz.

## 1. Introduction

The objective of optical instruments is to measure the intensity accurately without bias as to the incident polarization state. One approach to overcome polarization bias are so called spatial pseudodepolarizers, which divide the incident beam into a large number of varying and intermixed polarization angles. In space instruments for earth observation such as ESA's MERIS (ENVISAT) or OLCI (Sentinel 3), the Cornu-type depolarizer is currently used [1, 2]. It consists of a pair of 45 degree prisms of quartz crystal, optically contacted to form a cuboid. The fast axes are 90 degrees apart and 45 degrees from the sides of the depolarizer. Cornu-type depolarizers are available for broadband visible applications and work only for linearly polarized light.

Especially for space instruments, large-area and low-weight optical elements with stability against radiation and temperature are desirable. Metamaterials could advantageously replace bulky standard optical components like the Cornu-type depolarizer to achieve the same functionality but with higher efficiency and lower resources (mass and volume consumption). In this report we discuss metamaterial-based polarization scramblers that could be particularly used for earth observation in the spectral range between 400 nm and 1000 nm [3]. The transmission polarization scrambler presented uses metallic meander structures.

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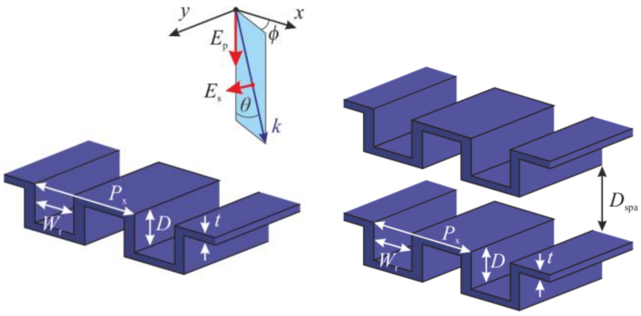
## 2. Polarization scramblers using single and double meander structures

The investigated polarization scrambler is based on so-called plasmonic meander structures, which are thin metal films corrugated on both sides with a thickness $t$, a corrugation depth $D$ and a periodicity $P_x$. To achieve inversion symmetry along the propagation direction of the incident light, the condition $W_r = P_x/2 - t$ has to be fulfilled, where $W_r$ is the ridge width. If two meander structures are stacked onto each other (Fig. 1b), the distance between them is labeled $D_{spa}$.



a) (b)

Fig. 1: (a) The meander structure is defined by the geometrical parameters thickness $t$, meander depth $D$ and periodicity $P_x$. (b) For a double meander structure, the distance between two sheets is defined as $D_{spa}$.

For a single meander structure we derived the Mueller matrix as:

$$M_{meander} = \frac{c^2}{2}\begin{bmatrix} 1 & \cos(2\phi) & 0 & 0 \\ \cos(2\phi) & 1 & 0 & 0 \\ 0 & 0 & \sin(2\phi)\cos(2\delta) & \sin(2\phi)\sin(\delta) \\ 0 & 0 & -\sin(2\phi)\sin(\delta) & \sin(2\phi)\cos(\delta) \end{bmatrix}. \qquad (1)$$

One clearly sees that all the elements containing the polarization angle $\phi$ become zero on average as soon as the meander structure is rotated along its normal axis continuously over time. Alternatively, the same averaging can be achieved by spatially distributing meander structures rotated by a random angle $\phi$ similar to the working principle of liquid-crystal depolarizers [4]. For both approaches all Mueller matrix elements would become zero except $m_{00}$ and $m_{11}$ and, thus, only partial depolarizing can be achieved. However, even with these two nonzero elements, incident light with any state of polarization can be depolarized (degree of polarization $P' = 0$) except the horizontally and vertically linearly polarized ones ($P' = 1$). Furthermore, the transformation between orthogonal polarizations due to strong plasmonic interactions is not yet considered in Eq. 1.

In the next step, the Mueller matrices are derived from full numerical calculations, which include all polarization transforming effects. We characterize the Mueller matrix of single and double layer meander structures as a function of the incident and azimuth angles $\phi$. It is assumed that the individual structures themselves do not have any depolarizing effect. Therefore, their Mueller matrices can be calculated directly from the Jones Matrix via the Jones-Mueller transformation [5, 6].

Fig. 2a shows an exemplary spectrum of a double layer meander structure with a period of $P_x = 400$ nm, a corrugation depth of $D = 40$ nm, a metal thickness of $t = 30$ nm and a cavity length of $D_{spa} = 600$ nm. In the Mueller matrix of this structure, the C2-symmetry is becoming more pronounced compared to the single meander structure (not shown) and a strong variation of the diagonal elements with $\phi$ can be observed (Fig. 2b). After averaging over $\phi$ we obtain $m_{11} = 0.5$, $m_{22} = 0.5$, and $m_{33} = 0.05$ for $\theta < 5°$ for 600 THz (which yields depolarization rates of 50%, 50% and 95% for linearly polarized light (LP), 45° linearly polarized light (LP45) and circularly polarized (CP) light, respectively). At the higher-frequency edge of the pass band at 650 THz, the diagonal elements are reduced down to $m_{11} = 0.4$, $m_{22} = 0.4$, and $m_{33} = -0.3$ for $\theta < 5°$. The corresponding depolarization rates for LP, LP45 and CP light are 60%, 60% and 70% (not shown). These preliminary results of the polarization scramblers employing double meander structures show that at least 60% of any polarized light can be depolarized. Some polarization states can be depolarized more efficiently. The meander structure that was investigated in Fig. 2a, for instance, scrambles circularly polarized light very efficiently with a depolarization rate of 95% at 600 THz.

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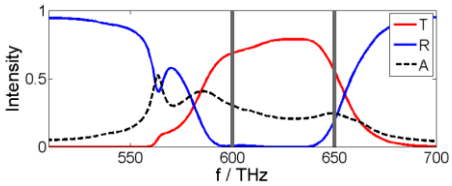
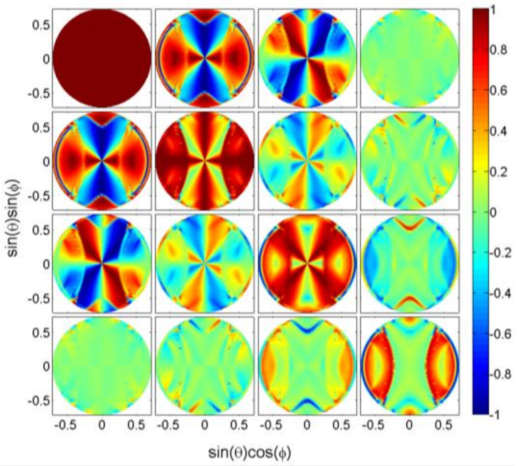
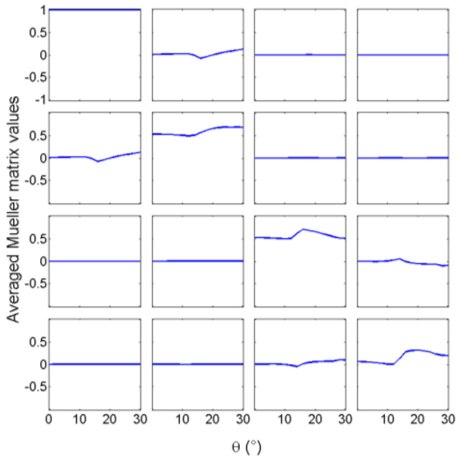



(a)




(b)




(c)

Fig. 2: (a) Spectrum of a double meander structure with period $P_x$ = 400 nm, corrugation depth $D$ = 40 nm, thickness $t$ = 30 nm and spacer thickness $D_{spa}$ = 600 nm (b) Mueller matrix (elements $m_{ij}$ with row index $i$ = 0, 1, 2, 3 and column index $j$ = 0, 1, 2, 3) of the same structure at 600 THz. (c) Mueller Matrix elements from (b) averaged over the azimuth angle $\phi$ from 0° to 180°.

## 3. Conclusion

We have shown numerically that polarization scramblers can be realized using metallic meander structures. These meander structures exhibit prominent optical properties such as linear polarization, phase retardation and polarization conversion due to the excitation of surface plasmon polaritons. The off-diagonal Mueller matrix elements of a polarization scrambler consisting of spatially distributed meander structures rotated by a random angle can be brought to zero for low incidence angles. At the higher frequency edge of a double meander pass band we obtained depolarization rates larger than 60% for linearly and circularly polarized light. To our knowledge, no available device can scramble all polarization states of monochromatic or narrow-band light scatter-free and in transmission. It is notable that we can design the presented scrambler according to particular requirements just by geometry variation. Left or right circularly polarized monochromatic light for instance could be depolarized by 95%. With further optimization, the presented polarization scrambler might be a good alternative to existing approaches and would be especially desirable for space applications due to its low weight, radiation stability and large-scale manufacturability.

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