Free Space Metamaterials

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One of the fundamental challenges in transmitting and routing microwaves in air is inevitable divergence because of diffraction, and the lack of guiding and beam steering “components” when the beam propagates in free space. Moreover, detection of radar signals in a realistic environment may be negatively affected by the divergence of the beam resulting from distortions by natural obstacles, e.g., by non-planar landscapes. To overcome the distortion of beams propagating in such environments, some way of guiding the beam around obstacles is necessary.

The development of ordered structures of laser-induced plasma filaments opens the possibility of creating conductive filamentary structures capable of guiding microwave frequency beams. In the last few years, various types of filament-based waveguides have been proposed for channeling microwaves [1-4]. While this approach offers a way to counteract the diffraction of a radar signal over some distance, the issues of beam steering and coupling microwave signals into such waveguides are likely to be challenging.

We proposed a fundamentally new approach based on unique physical properties of virtual hyperbolic metamaterials formed of plasma filaments in air [5]. We show that these structures can be used for focusing, guiding and steering radar signals to facilitate new degrees of freedom in the detection of such signals in realistic environments. Conventionally, hyperbolic metamaterials are realized using either metal/dielectric multilayers or an array of metal wires in a dielectric matrix. Here, we show that an array of plasma filaments formed by the propagation of intense short pulses in air is able to form a virtual hyperbolic metamaterial structure. Indeed, plasma filaments play the role of metal wires and the air plays the role of a dielectric host.

In summary, in this work we show that virtual hyperbolic metamaterials can be used to reduce microwave beam divergence, route beams around the obstacles, and improve angular resolution of microwave radars.

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