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Silica Glass Spheres as Omnidirectional Microwave Retroreflectors

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A retroreflector is a device that reflects an incoming radar wave back to the source. Microwave retroreflectors (radar reflectors) are widely used in microwave applications, for example, for calibrating antennas, marking vessels, buoys, airfield runways and power lines as well as for modifying radar cross section of military vehicles. Typical retroreflectors are metal spheres and plates, dihedral and trihedral (corner) reflectors as well as Luneburg lenses. A common problem of the mentioned devices is however that except for metal spheres their operation is limited in orientation (elevation and azimuth) range, namely to a line normal to the surface of the metal plate, a plane perpendicular to the edge of the dihedral reflector, a spatial sector of about 90° corresponding to the aperture of the corner reflector or 180° for the Luneburg lens. Luneburg lenses require a graded-index material stratification in their interior, which complicates their manufacturing, particularly for higher frequencies beyond the X band, and have to be metallized on the back side, which principally limits their spatial coverage. Metal spheres are perfectly omnidirectional but rather weak reflectors as their reflection comes from the small vicinity of a single point on their surface.

Homogeneous dielectric spheres are typically weak reflectors too, and a metallization of a portion of their surface is necessary to improve their performance, similarly to the cat's eye optical reflectors. A spectacular exception is a sphere from silica glass [1]. At microwave frequencies (e.g., between 1 GHz and 100 GHz) the relative permittivity of silica glass is about 3.8 with very small losses (lost tangent about 5×10^{-4}), which results in focusing of the incoming plane electromagnetic wave close to the back side of the sphere, almost unattenuated propagation inside the sphere and in strong reflection from the concave material boundary. The backscattered wave is formed by a ring of rays, all upon a single interior reflection and all being in phase, which is another reason for much stronger reflection compared with an equivalently sized metal sphere. The backscattering cross section of a lossless dielectric sphere is proportional to the frequency, implying increasing performance at growing frequencies. It is worth noting that at optical frequencies, permittivity of silica glass is significantly different (about 2.13) and the spheres reflect much weaker. The paper will describe microwave properties of silica glasses, the theory of electromagnetic scattering from low-loss dielectric spheres and the results of experimental studies of the silica glass spherical retroreflectors.

1. A. V. Osipov, "Method and Device for Sensing a Spatial Region by Means of Radar Waves," patent Nr. 10 2019 209 508 granted by German Patent Office on 19.02.2024.