Omnidirectional Retroreflectors for Microwave Applications

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A retroreflector is a device which reflects an incoming electromagnetic wave predominantly back to the source. The reflection should be strong, predictable and largely independent of the incidence direction. At microwave frequencies, retroreflectors are used for calibrating radars, guiding air vehicles, marking buoys and small boats to enhance their radar visibility, etc. Conventional microwave retroreflectors are metal spheres and plates, corner reflectors and Luneburg lenses [1]. Their backscattering cross section (RCS) σ follows the approximate relation

$$\sigma = C(fD)^m D^2, \quad (1)$$

where D is the size of the reflector, f is the frequency, C is a coefficient and m is either 0 (metal sphere) or 2 (plates, corner reflectors, Fresnel lenses). The problem is however that a metal sphere, though being perfectly omnidirectional, is a relatively weak scatterer, whereas the functionality of other reflectors is principally limited in space to either a single direction (plate), or a 90° sector (corner reflector), or a hemisphere (Luneburg lens).

This work describes a new class of microwave retroreflectors – omnidirectional but reflecting substantially stronger than the metal sphere and with RCS following (1) with $m = 1$. Two basic designs are proposed: a homogeneous sphere from silica glass [2] and a spherical dielectric shell with an optimally chosen shell thickness [3]. A plane wave incident on the homogeneous sphere – upon refraction into the interior of the sphere, reflection at the backside and refraction back into the surrounding medium – creates *a ring of rays* scattered back to the source. The ring is a one-dimensional continuum of rays, which results in much higher RCS values compared with the metal sphere reflecting just a single ray back to the source. The permittivity of the silica glass ($\varepsilon_r' = 3.81$ and $\varepsilon_r'' \approx 0.002$ over the whole microwave range) ensures much higher RCS values compared with other dielectric materials (Table 1). In contrast to optical frequencies, metallization of the backside of the sphere is not required, which makes the design perfectly omnidirectional.

Table 1. RCS of a sphere with $D = 5$ cm averaged over the band from 77 GHz to 81 GHz

Material	Silica glass	Polyamide	Teflon	PEC	Acrylic glass	Standard glass
RCS (cm^2)	876	57	43	19	16	4

In the case of the shell design, multiple rings of rays are backscattered according to the number of reflections inside the shell. The main contributions come from the double and triple reflection, and their overlapping results in a strongly oscillating dependence of RCS on the frequency with very high peaks, low minima and high average values. Backscattered signal can be dramatically enhanced by tuning the thickness of the shell.

RCS of the proposed retroreflectors quickly increases with the growing diameter D of the sphere. For example, a silica glass sphere with $D = 12$ cm ensures an RCS value about 1 m^2, which is more than 10 times greater than RCS with $D = 5$ cm (Table 1). Even greater RCS values can be achieved with the shell design when the latter is realized as an inflatable balloon of a large diameter. For example, a balloon with a 4 mm thick rubber ($\varepsilon_r' = 2.37$, $\varepsilon_r'' = 0.01$) wall and $D = 6$ m leads to peak RCS values around 2000 m^2 and the average RCS value of 480 m^2 over the frequency range from 8 GHz to 12 GHz.

1. E. F. Knott, J. F. Shaeffer and M. T. Tuley, *Radar Cross Section*, Artech House, 1993.

2. A. V. Osipov, "Method and Device for Sensing a Spatial Region by Means of Radar Waves," Patent Publication Number: WO/2020/260372, Publication Date: 30.12.2020 (patent pending).

3. A. V. Osipov, "Method and Device for Sensing a Spatial Region by Means of Radar Waves," Patent Publication Number: WO/2021/122361, Publication Date: 24.06.2021 (patent pending).