4^{th} URSI AT-RASC, Gran Canaria, 19-24 May 2024

Salisbury Screen under Oblique Illumination and Experimental Characterization of Thin CNT Coatings

Andrey V. Osipov*, Erik Buchenau, and Thomas Jagdhuber
German Aerospace Center (DLR), Microwaves and Radar Institute, 82234 Wessling, Germany; e-mail: Andrey.Osipov@dlr.de

Salisbury screen is a widely used absorbing structure for microwaves [1]. The structure is a resonant absorber created by placing a resistive sheet in front of a metal plate [2]. The sheet and the plate are separated by a layer of dielectric material (spacer) to hold the structure together. At normal illumination of the absorber, the amplitude of the reflection coefficient has minima at the frequencies $f_n = c(2n+1)/(4d)$, where d is the thickness of the spacer, c is the speed of light in the material of the spacer and $n = 0,1,2,\ldots$ The depth of the minima is determined by the ratio R_e/Z_0, where R_e is the resistivity of the sheet and Z_0 is the intrinsic impedance of the surrounding medium ($Z_0 \approx 120\pi$ ohm in air), such that the reflection vanishes when $R_e = Z_0$. Theoretical studies of the structure are mostly based on thin-sheet transition conditions and limited to the case of normal incidence. Some aspects of the problem of oblique incidence have been addressed in [3,4]. One possible realization of the Salisbury absorber is a spray coating with carbon nanotube inks (CNT) on a dielectric substrate, e.g. glass. By measuring the return loss of this absorber, it is possible to determine the sheet resistance of the CNT coating [5].

In this paper we show (a) how and under which conditions the thin resistive sheet approximation follows from the exact solution for a plane electromagnetic wave obliquely incident on a homogeneous magneto-dielectric lossy layer, (b) present reflection coefficients of the Salisbury screen for parallel and perpendicular polarization in an explicit form and (c) study the dependence of the resonance frequency and the depth of the minima on the incidence angle and polarization. For example, when the electromagnetic properties of the spacer are close to the air and the sheet is non-magnetic, it can be shown that

$$f_{\min}(\theta_{\text{inc}}) = \frac{f_n}{\cos\theta_{\text{inc}}}, \quad \left|R_\parallel\left(\theta_{\text{inc}}, f_{\min}(\theta_{\text{inc}})\right)\right| = \left|\frac{R_e - Z_0\cos\theta_{\text{inc}}}{R_e + Z_0\cos\theta_{\text{inc}}}\right|, \quad \left|R_\perp\left(\theta_{\text{inc}}, f_{\min}(\theta_{\text{inc}})\right)\right| = \left|\frac{R_e\cos\theta_{\text{inc}} - Z_0}{R_e\cos\theta_{\text{inc}} + Z_0}\right|,$$

where θ_{inc} is the incidence angle, f_n is a design frequency (resonance frequency at $\theta_{\text{inc}} = 0$), $f_{\min}(\theta_{\text{inc}})$ is the resonance frequency at θ_{inc} and $R_\parallel(\theta_{\text{inc}}, f)$ and $R_\perp(\theta_{\text{inc}}, f)$ are reflection coefficients for the parallel and perpendicular polarization at θ_{inc} and the frequency f. When $\theta_{\text{inc}} = 0$, $f_{\min}(\theta_{\text{inc}})$ coincides with f_n. It is important to point out that the resonance frequency depends on θ_{inc} but is identical in both polarization cases. With the exception of the perfect Salisbury screen ($R_e = Z_0$), the depth of the reflection minimum is in general polarization-dependent, and it is impossible to let reflection vanish for both polarizations simultaneously. Furthermore, we show how the Salisbury screen can be used for experimental determination of the sheet resistance R_e. For example, using a metal-backed low-absorption glass plate with a CNT coating on top permits specification of R_e as a function of frequency, which may be significantly different from the usually available DC values.

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