Modeling OAM Transmission in Waveguides with COMSOL Multiphysics®

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Abstract

In the last few years much research in the context of telecommunications has been directed towards the possibility of enhancing the information transfer per unit bandwidth by exploiting the Orbital Angular Momentum (OAM) of light [1,2]. However, it is well known that the free-space propagation of OAM beams is affected by an over-quadratic power decay with distance [3]. Guided propagation is instead free from this limitation. This fact has strongly favored the applicability of OAM modes in optical guiding media, as widely reported in literature [4,5]. An application of guiding principles for OAM modes in the RF range could thus be in waveguided scenarios. With the aim of the software COMSOL Multiphysics®, we have analyzed the propagation of suitable OAM superpositions of waveguide eigenmodes [6] in circular and coaxial guiding structures. In particular, COMSOL proved essential in the estimation of the power attenuation constants due to the finite conductivity of the metallic guide walls.

The analytic expressions of the OAM modes were derived by properly combining the well-known TE and TM solutions of the Maxwell's macroscopic equations relative to two different geometries: the circular waveguide and the coaxial cable. Modes carrying OAM are represented by superpositions of the form: TEmi ± iTEmi (or similarly TMmi ± iTMmi) [6], where the index m is related to the total angular momentum carried on average by each photon in the waveguide, including both an OAM and a SAM (Spin Angular Momentum) contribution. In order to determine the cut-off frequency for each of the considered mode, the eigenvalues and the corresponding propagation constants were computed with the help of the software MATLAB®. All COMSOL simulations were carried out via the RF module and the OAM modes were implemented by directly inserting the analytic expressions of the electric field in the model ports, placed at the opposite ends of the guiding structures. By means of a parametric sweep in the guide length, we were able to extract the attenuation constants relative to the propagation of several OAM modes.

As a first step, the software COMSOL Multiphysics allowed us to prove that real circular waveguides and coaxial cables support the propagation of OAM modes (see Figure 1 and 2). Then we focused on the case of a circular guiding structure filled with air, with walls made of copper. The well-known exponential power attenuation law due to ohmic losses has been verified by computing the S21 parameter for different values of the circular waveguide length (see Figure 3). Such procedure led to the estimation of the power

attenuation constants for each of the considered OAM modes by means of a linear fit of the computed values (Figure 3). Finally, starting from the analysis of the OAM propagation in a coaxial guide, we tried to excite OAM solutions on a metal wire with dielectric coating (Goubau line) [7] coupled to coaxial horn structures (Figure 4).

Reference

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Figures used in the abstract

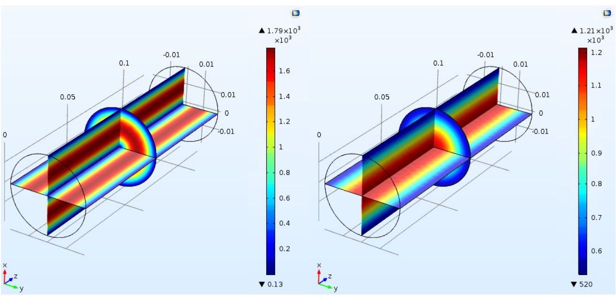

Figure 1: Circular waveguide with copper walls and radius a = 2 cm. Left: electric field norm for the eigenmodes superposition TE01 - iTE01 (m = 0); right: electric field norm for the eigenmodes superposition TE11 - iTE11 (m = 1). The frequency is fixed at f = 10 GHz.

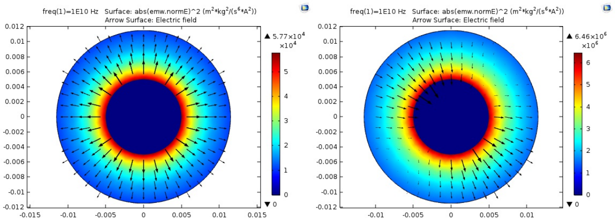

Figure 2: Coaxial waveguide with copper conductors and Teflon dielectric. Left: electric field norm for the TEM fundamental mode (m = 0); right: electric field norm for the eigenmodes superposition TE11 - iTE11 (m = 1). The frequency is fixed at f = 10 GHz.

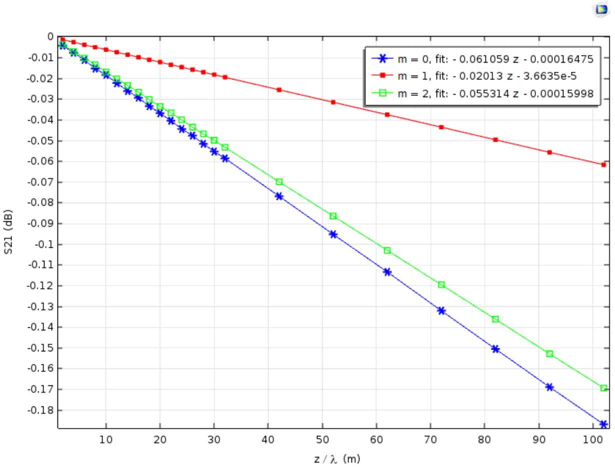

Figure 3: S21 parameter as a function of the guide length z for a circular waveguide with copper walls and radius a = 2 cm. The corresponding linear fit results are reported in the legend.

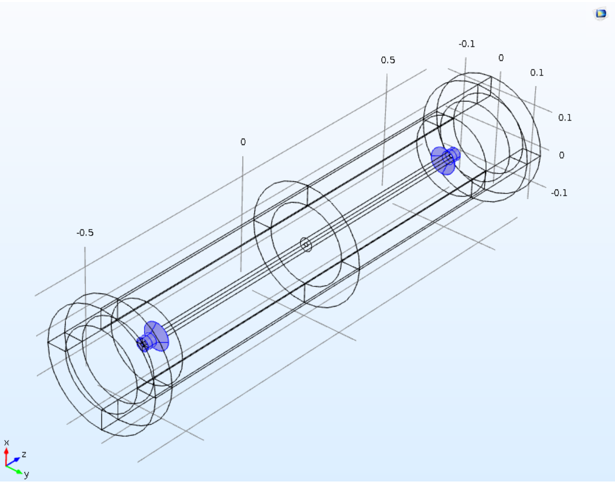

Figure 4: COMSOL geometry for a Goubau line with coaxial horn launcher and receiver.