Medium-Range Propagation Flexible Waveguides at Millimeter-Wave and Submillimeter-Wave Frequencies

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Abstract—**This contribution presents the development of medium range flexible propagation waveguides for next generation wired data systems at millimeter and sub-millimeter wave frequencies.**

I. INTRODUCTION

NEXT generation communication systems (i.e., 5G) would greatly benefit from the availability of flexible, low-loss cables to allow routing the large amount of wireless forecasted data to the optical fiber backbone infrastructure. Current solutions employed in the microwave regime, i.e. coaxial cables, cannot be scaled at higher frequencies, because they suffer from high losses arising from the finite conductivity of metals and absorption of dielectric materials [1, 2]. In the infrared and optical regime, the commonly used fibers, i.e. Bragg fibers [3, 4], employ core diameters which can be in the order of 50-120λ, not allowing its scalability at lower frequencies. The current existing solutions in literature for terahertz frequencies are based on coating hollow waveguides [5-7]. However, these solutions use highly over-mode cores to achieve low losses and thus are not robust towards bending. This contribution will present a geometry allowing to achieve low-loss (i.e., 1-2dB/m), bendable waveguides with small (i.e., 2-3λ) outer diameters based on a metal-dielectric electromagnetic bandgap (EBG) waveguide [8] compatible with realistic fabrication methods for a wide range of frequencies in the millimeter and submillimeter bands.

II. FLEXIBLE WAVEGUIDES

The proposed waveguide is composed of an air core and a series of dielectric layers alternating high and low impedance providing field confinement inside the core. A metallic cover encloses the structure to further avoid the field leakage outside the waveguide. The propagation mode employed is the TE_{01}, due to its low-loss characteristics. In order to minimize the TE_{01} to TM_{11} mode degeneracy, which would prevent bending of the waveguide due to the increased losses, an optimization of the layer separation and thickness is performed [8].

An analytical tool based on the use of the spectral Green's function of cylindrical stratified media that allows the calculation of the fields, transmission and bending losses based on [8, 9] has been employed in order to perform the optimization of the design for a wide range of frequencies in the millimeter and submillimeter-wave spectrum. The tool provides indicatively a 90% time reduction compared to 3-D full simulators, thus allowing to perform the design and optimization of the structure significantly faster. The optimization tool takes into account the bending radius of the waveguide which have been calculated using [10].

An example prototype has been designed and fabricated in the W-band using standard 3-D printing. The waveguide core is chosen to be air, in order to lower the dielectric absorption losses, and the high and low impedance layers are realized, alternating in the 3-D printing process dielectric and air. The different dimensions have been optimized to balance, for the intended application, the existing tradeoff between the bending radius (around 5cm), the transmission loss (around 2dB/m) and the outer waveguide diameter (around 1cm), see Figure 1.

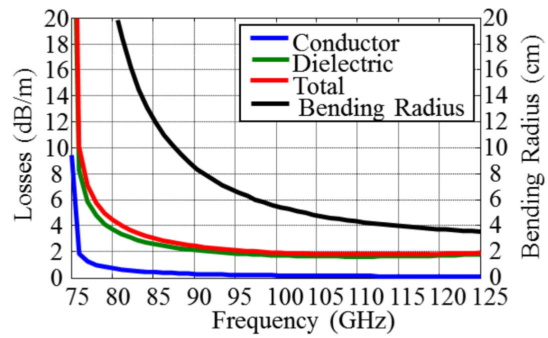

Figure 1. (Left Axis) Conductor, dielectric and total transmission losses as a function of the frequency of the W-band design. (Right Axis) Bending radius in cm in order to achieve 1dB loss in the bend.

The fabricated prototype is shown in the photograph of Figure 2. Good accuracy and resolution have been achieved using this fabrication method for this band. However, the lossy materials employed and its current fabrication resolution limit its use at higher frequencies. At submillimeter wave frequencies other techniques should be employed, i.e. fiber extrusion techniques [11]. Fiber extrusion techniques, which have been widely used in the optical domain and now in the infrared, have a great potential for being employed at THz as they provide enough resolution and accuracy, as well as the possibility to use a wide range of low loss dielectrics.

Figure 2. Photograph of a W-band prototype fabricated using 3-D printing.

This contribution will present a full analysis of the performance, challenges and tradeoffs of this proposed EBG structure in a full range of frequencies covering from 50GHz up to 1THz, including its comparison with the existing literature. It will also include the evaluation and study of the fabrication methods that can be employed within this range of frequencies.

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