Study of Cylindrically Periodic Dielectric Waveguides at Submillimeter Waves

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***Abstract*—This work studies the viability of using waveguides made of concentric cylindrical periodic dielectrics for propagating at submillimeter waves. Such kind of waveguides has an air core where most of the power is confined allowing a low propagation loss.**

I. Introduction And Background

In the submillimeter and terahertz bands strong inherent dielectric absorption in solids and high skin-depth losses in conductors make it difficult to realize single mode propagating structures with low loss. Traditionally, low loss waveguides (WG) have been realized with oversized hollow cores where many modes are above cut-off and they may easily be excited, as in case of bends. Recently the high dielectric constant ribbon has shown very low losses [1], however it presents substantial radiation losses at any sharp bends if no coating is used [2]. WGs that are cylindrically periodic, see Fig. 1, have shown very low loss in the infrared bands [3], and its propagating mode resembles that of the metallic circular WG [4]. In this work we studied the properties of CPWGs by calculating the leaky wave poles of the pertinent spectral Green's function. The mode distribution can then be obtained by applying the theory of residues. The results are validated with simulations in HFSS. Dielectric and radiation losses are also considered. Fabrication of these CPWGs with a large number of layers and high dielectric constant materials is not possible at the present time at these frequencies. Therefore an alternative structure with a small number of layers is also studied, wherein the periodic stratification is terminated at a predetermined position in a metal wall. This eliminates the radiation loss but adds a modest loss contribution from the metal. Finally, simulations with CST MS are used to study the bend effects.

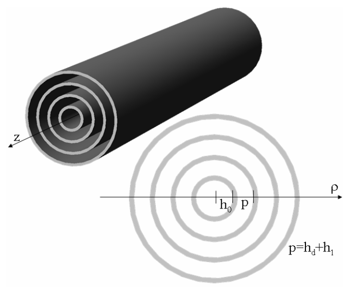

Fig.1: CPWG Geometry

II. Results

The CPWG has a period of $p=h_d+h_1$, where h_d is a quarter of the wavelength in the dielectric and h_1 is a quarter of the wavelength in free space. Since the structure is open, the waveguide mode is leaky with complex propagation constant associated to radiation losses. This loss can be reduced by increasing the numbers of layers or by bounding the periodic structure by metal. The electric field of a CPWG is shown in Fig.2 and compared with HFSS simulations. If a lower dielectric constant is used (εr=3.8) the power traveling on the second air layer is increased. If a metal boundary is placed at the beginning of the next period, the field distribution remains the same. The conductor and dielectric losses can be calculated by using the conventional perturbation formulas. For example for a CPWG with εr=3.8, P=3, tanδ=1e-4 and σ=1e7S/m, the loss is 7dB/m at 775GHz, much lower that the one of a standard single mode CWG in the order of 250dBs/m. A bent CPWG with a single closed period has been simulated with CST MS. Figure 3 shows the electric field distribution for a 10λ radius bent in the H and E planes. The CPWG mode in the H bent is not altered (a coupling into other modes will start for a 5λ radius bent), while the E bent creates a small coupling to other modes.

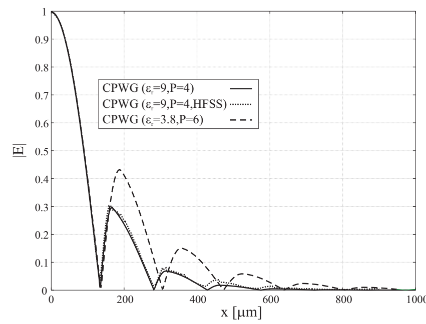

Fig.2: Electric field distribution for several dielectric constants and periods (P)

References

[1] C. Yeh, et. al.; "Communication at millimeter-submillimetre wavelengths using a ceramic ribbon", Nature, vol. 404, April 2000.

[2] C. Yeh, F. Shimabukuro, P. H. Siegel, "Low-loss terahertz ribbon waveguides", Applied Optics, vol. 44, no.28, Oct. 2005.

[3] B. Temelkuran, S. D. Hart, G. Benoit, J. D. Joannopoulos, Y, Fink, "Wavelength-scalable hollow optical fibres with large photonic bandgaps for CO2 laser transmission", Nature, vol. 420, Dec. 2002

[4] M. Ibanescu, S. G. Johnson, et. al. "Analysis of mode structure in hollow dielectric waveguide fibers", Physical Review E 67, 2003.

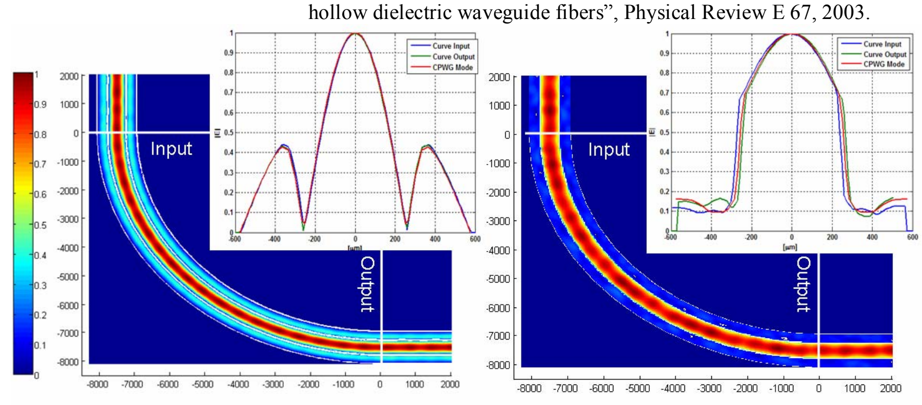

Fig.3: Electric field distributions for H (left) and E (right) bends

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