Dielectric Fiber Based Splitters, Couplers and Endoscopes for sub-THz Frequencies

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Abstract—**Dielectric fibers work as low loss waveguides for sub-THz frequencies. We evaluate the potential of a polyethylene fiber with a diameter of 3 mm for different waveguiding applications at frequencies between 70 and 110 GHz. The attenuation is as low as 0.03 dB/cm at 70 GHz. Results of a 3-dB coupler and a 1x4 splitter are shown. Furthermore, the waveguide can also be used as an endoscope.**

I. Introduction And Background

DIELECTRIC fibers have been shown to work effectively as low loss waveguides at THz frequencies. They are superior to metal waveguides because of their flexible structure and lower losses [1]. Considerable work has been done in this field by R. Mendis et al. [2], who investigated plastic ribbon structures and L. J. Chen et al. [3], who used sub-wavelength fibers for terahertz wave guiding. Here, we use a circular rod-like structure with a diameter of 3 mm, which works as a single-mode fiber for 70 GHz and becomes multimode for higher frequencies. Because of the diameter, which is in the same dimension like the wavelength, more radiation is guided inside the core compared with a sub-wavelength fiber. The investigated waveguide is insensitive to touching or any other contact and therefore well suited for many practical applications, for example a THz endoscope. This paper aims for the characterization of the dielectric fiber and the investigation of further fiber based devices.

II. Results

The waveguide was investigated at frequencies between 70 and 110 GHz using a network analyzer (Agilent Technologies PNA Series Network Analyzer E8361A with extension N5260A). It is driven with -15 dBm output power. The waveguide has a diameter of 3 mm. It was directly attached to the horn antenna (cf. Fig. 2) and exhibits an attenuation of 0.03 dB/cm at 70 GHz, which is comparable with the values mentioned in [3]. The measured dispersion is so low that it can be neglected. The waveguide has also been tested with a frequency multiplied Gunn oscillator to work effectively for frequencies up to 300 GHz, when the waveguide becomes multimode.

Besides dielectric fibers also fiber based devices are necessary for many practical applications. In this regard directional couplers, power splitters and combiners are of substantial interest. A 3-dB coupler was constructed by two side by side lying polyethylene waveguides. The evanescent field of the first fiber couples in radial direction to the second fiber. The coupling ratio can be adjusted by changing the coupling length. Measured results (scattered squares and triangles) are shown in Fig. 1 for a frequency of 90 GHz and a coupling length between 0 and 22 cm. A periodic power exchange between the direct and the coupled fiber can be observed. The polyethylene fiber supports up to 5 modes at a frequency of 90 GHz. However, higher order modes with lower propagation constant are likely to radiate out of the core and hence most power is carried by the fundamental mode. Simulation results based normal mode theory are plotted in Fig. 1 (dashed and dotted line). There is a good agreement between measurement and simulation. The coupling coefficient is calculated to be k = 0.039 1/mm.

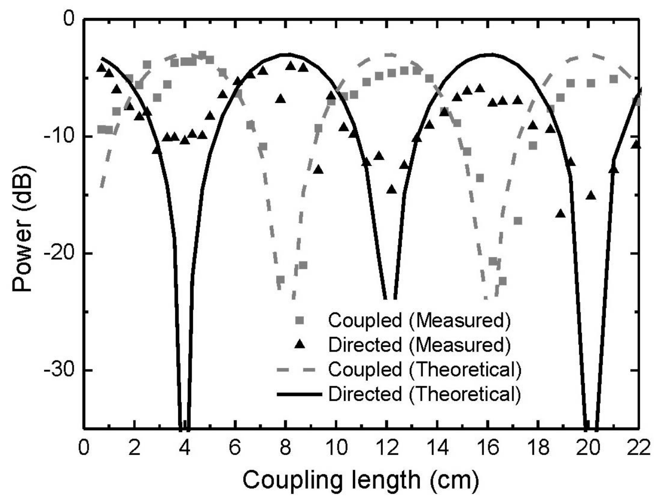

Fig. 1: Measured and simulated power exchange in a 3-dB coupler for 90 GHz between direct and coupled arm.

Splitters with multiple outputs or combiners with multiple inputs can be derived by cascading several 3-dB coupler. However, more desirable is the development of a bulk component. A 1x4 splitter/combiner based on the self-imaging principle [4] was realized from a rib waveguide structure. The input field profile is reproduced in multiple images at periodic intervals along the propagation axis of the multimode waveguide. The rectangular rib waveguide was cut at the first four-fold image at a distance of 53.1 mm. The 1x4 splitter consists of a 20 mm x 53.1 mm x 3 mm (length, width, height) rib structure which is center fed at the front surface by a 3 mm round polyethylene waveguide. The input power is equally distributed into the four fibers at the back surface of the splitter. The measured excess loss and the imbalance are as low as 1.63 dB and 0.9 dB, respectively. Splitters and couplers can be used for several applications like for example a 3-dB coupler for the construction of THz endoscopes.

Dielectric fibers can be in particular very useful for imaging application, which are normally difficult to access. The inset of Fig. 2 depicts the use of the polyethylene fiber as part of an

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endoscope. Sub-THz radiation at 100 GHz is launched into the fiber with a horn antenna. The fiber guides the radiation around the large metal plate to the sample. The metal plate blocks the line of side connection between the transceiver and the sample. The latter on is in our case a small metal plate with holes of 2 mm diameter. The sample is raster scanned in x- and y-direction across the end of the fiber. The reflected radiation is guided back through the same fiber to the transceiver head. Fig. 2 shows the measured pattern. The black spots in the image indicate a low reflection at the spatial position of the holes in the sample. The metal structure around the holes leads to high reflection, which can be seen in the white area of the image.

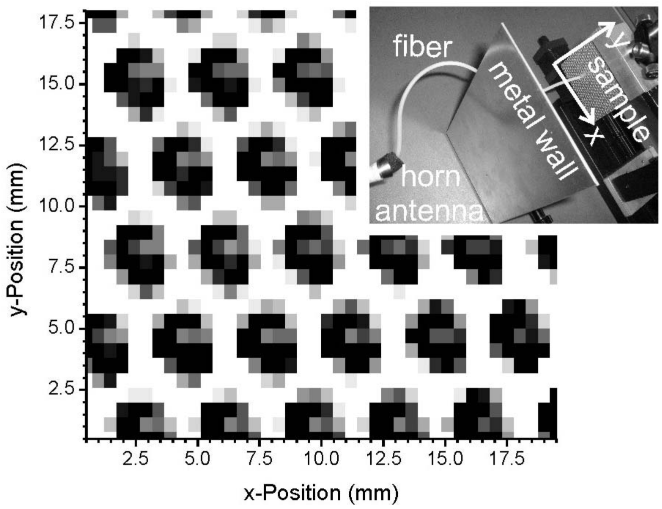

Fig. 2: Reflected THz signal at 100 GHz measured with the THz endoscope shown in the inset.

In case of separated transmitter and receiver units a 3-dB coupler as described above can be applied to guide the reflected signal to the receiver.

III. Conclusion

We have demonstrated the use of dielectric fibers to guide sub-THz radiation between 70 and 110 GHz. The fibers have also been tested to work with low losses at frequencies of 300 GHz. We successfully constructed a 3-dB coupler and a 1x4 splitter, which allow for power division with low imbalance and low insertion losses. Such fibers and splitters are well suited for imaging applications in THz endoscopes. We thank T. Kleine-Ostmann and C. Jastrow from PTB in Brauschweig for giving us the opportunity to work with their 300 GHz oscillator system.

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