Terahertz Communications using Subwavelength Solid Core Fibers

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***Abstract*— Terahertz (THz) band is the next frontier for the ultra-high-speed communication systems. Currently, most of communications research in this spectral range is focused on wireless systems, while waveguide/fiber-based links have been less explored. Although free space communications have several advantages, the fiber-based communications provide superior performance in certain short-range communication applications. In this work, we study the use of subwavelength dielectric THz fibers for information transmission. Particularly, we use polypropylene-based rod-in-air subwavelength dielectric THz fibers of various diameters (0.57-1.75 mm) to study link performance as a function of the link length of up to ~10 m, and data bitrates of up to 6 Gbps at the carrier frequency of 128 GHz. Furthermore, we compared the power budget of the rod-in-air subwavelength THz fiber-based links to that of free space communication links and we demonstrate that fiber links offer an excellent solution for various short-range applications.**

***Keywords*— Terahertz communications, Millimeter wave measurements, Optical waveguides**

I. Introduction

Terahertz frequency spectrum (0.1 THz-10 THz) holds high promises for many applications that include communications, imaging, sensing and spectroscopy. In communications, in order to meet the bandwidth demand set by the next generation of wireless systems, a shift in the carrier frequency towards the THz band is unavoidable [1]. THz communications have been already demonstrated in the context free-space wireless links that profit from the presence of several low/modest-loss atmospheric transmission windows. Although there are many advantages of wireless communications including convenience in mobility for the end user, ease in scaling up the network, flexibility of device interconnectivity etc., they also possess many challenges. Particularly, due to high directionality of the THz beams THz wireless links are known for their high sensitivity to alignment errors, thus requiring careful positioning of the transmitters and receivers. Moreover, reliable communications in non-static environments (ex. between moving object) require complex beam steering solutions and free space links have higher chances of eavesdropping thereby increasing the risks for secure communications. Finally, the atmospheric weather conditions such as rain, snow, fog etc. play a major role in affecting the performance and reliability of the wireless THz links. In view of these limitations of wireless THz communications, short-range THz fiber links (~10 m) can offer an alternative solution as THz fibers present a closed highly controlled propagation environment, they can span complex geometrical paths, and they can offer reliable coupling to receiver and transmitter for both static and dynamic applications. For example, the THz fiber links offer reliable delivery of high-speed data through a partially blocked or geometrically complex areas, which is of importance for hard-to-reach or highly protected environments such as enclosures for aggressive environments (ex. bio-enclosures), protected structures (ex. shelters and bunkers), as well as for intra- and inter-device THz communications where different parts of the same system can be conveniently linked using flexible fibers.

In order to achieve an efficient THz guidance with low loss and low dispersion, the selection of proper waveguide material plays a major role. For geometrically complex links with low power budget (<0 dBm), dielectric waveguides are preferred over the metallic waveguides due to efficient coupling and waveguide sealed design [2]. Many polymers possess almost constant refractive index (RI) and low absorption losses at lower THz frequencies (<300 GHz). Polypropylene (PP), in particular, has one of the lowest losses over the THz frequency range. In this work, we present a simple rod-in-air dielectric THz subwavelength fiber for a short-range (~10 meters) communications link and up to 6 Gbps data speeds.

II. Experiments and Results

To study the performance of rod-in-air subwavelength fibers, we used PP filaments of three different diameters (D=1.75 mm, 0.93 mm and 0.57 mm) that are extruded using FDM printer with nozzles of different size. Optical characterization of the fibers were then carried out using an in-house photonics-based THz communication system detailed in [3] that operates at 128 GHz carrier frequency.

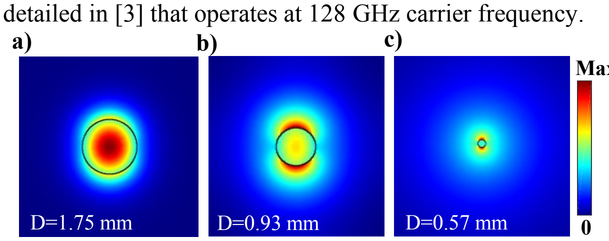

Fig.1 The normalized electric field profile of the fundamental mode at the carrier frequency of 128 GHz (a) 1.75 mm fiber, b) 0.93 mm fiber and c) 0.57 mm fiber.

Mode analysis of the rod-in-air fibers was carried out using commercial finite element software COMSOL Multiphysics. The normalized electric field distribution of the fundamental HE_{11} mode for the PP fibers of different diameters at 128 GHz are shown in fig.1 (a), (b) and (c). We see that, for the fibers with larger diameter, the modal field is mostly confined within the fiber, while for smaller diameters the modal fields are strongly present in the low-loss air cladding, which is also the reason for lower absorption losses of smaller diameter fibers.

The bit error rate (BER) measurements were carried out to study the performance of the fiber in a real-time communication. A non-return to zero (NRZ) pseudo random bit sequence (PRBS) with the bit rate varying from 1 Gbps to 6 Gbps is used as the baseband signal. An 8-meter long 1.75 mm fiber is butt coupled to the emitter and detector unit (along with horn antennas). Beyond 8 meters, the eye amplitude for 1.75 mm fiber is too low to record the BER for the given input power and therefore the maximum link length is fixed to 8 m. First, the BER measurement is carried out for 1.75 mm fiber by varying the bit rate from 1 Gbps to 6 Gbps.

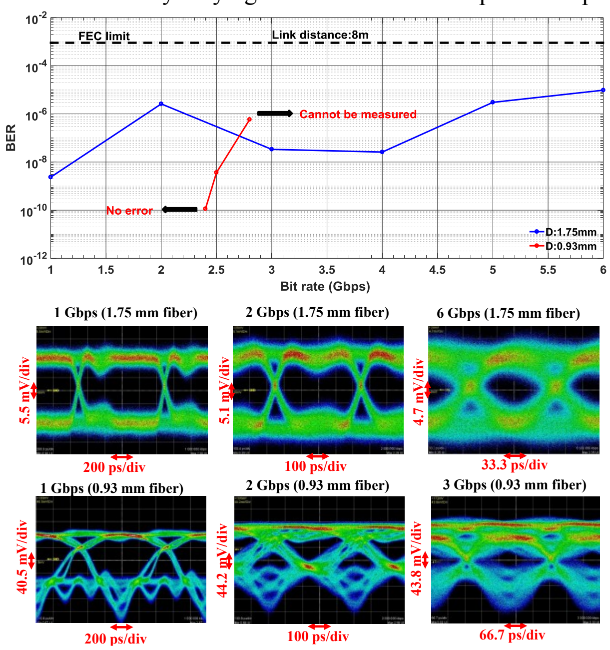

Fig.2.Measured BER Versus bit rate for the 1.75 mm fiber and 0.93 mm fiber for the link length of 8 m. The corresponding eye patterns are shown in the inset.

The total BER of 1.75 mm fiber in an 8 m link is presented in fig.6 (blue solid line). Similarly, an 8 m long 0.93 mm fiber is fabricated by reducing the diameter of 1.75 mm fiber using a 3D printer (Raise3DPro2). Next, the BER measurement for 0.93 m fiber is carried out. In the measurements, we did not observe any error (using optimized decision threshold) for the bit rate below 2.4 Gbps, within the measurement duration. The BER could not be able to measure for the bit rate beyond 2.8 Gbps due to high modal dispersion for this fiber at the given carrier frequency. The BER is recorded for the bit rate from 2.4 Gbps to 2.8 Gbps and is presented in fig.2 (red solid line). The inset in fig.2 shows the recorded eye pattern for both 1.75 mm and 0.93 mm fiber respectively. Next, a 10 m long PP fiber with the diameter of 0.57±0.03 mm is fabricated. Similar fiber alignments were carried out and optimized. The BER measurements were carried out from 1 Gbps to 6 Gbps. There is no error (within the measurement duration for target BER of 10^{-12}) up to 4 Gbps for the optimized decision threshold which is shown in fig.3. The inset in fig.3 presents the eye patterns for 1, 2 and 6 Gbps using 0.57 mm fiber.

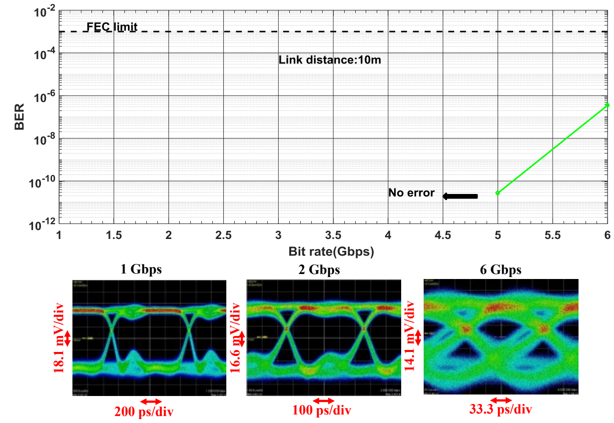

Fig.3. Measured BER using 0.57 mm fiber at a link length of 10 meters. The inset presents the eye patterns for 1,2 and 6 Gbps.

To present the advantage of the fiber-based communication link, it is compared with the free space communications as shown in fig.4. While using the horn antenna (aperture size of 10.8 mm) alone at both emitter and detector ends, the performance of the 1.75 mm fiber-based communication link is superior in terms of received power for the link length of at least 20 m. By reducing the fiber diameter, the modal loss can be further reduced thereby increasing the link distance even with low power THz sources.

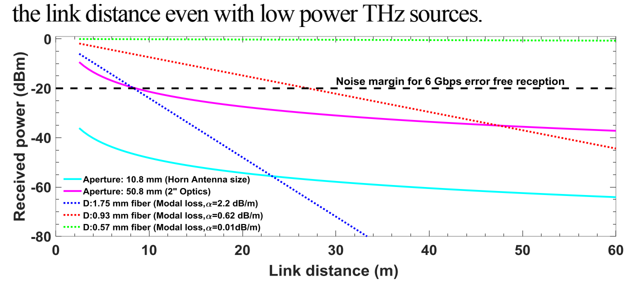

Fig.4. Comparison of the rod-in-air THz fiber-based link having different modal losses with the free space link which uses the aperture size of 10.8 mm (size of horn antenna) and a standard 2'' lens for the carrier frequency of 128 GHz. The transmitted power is considered as 0 dBm.

III. Conclusion

To summarize, we proposed and studied the performance of a simple rod-in-air dielectric THz subwavelength fibers of different thickness for a short-range communications application at the carrier frequency of 128 GHz. We showed that, depending on the thickness of the fiber, the performance is limited by either dispersion or modal propagation loss. Finally, we compared the THz fiber communication links with free space link and concluded that the performance of the THz fibers is superior in several short distance applications.

References

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