A metal wire waveguide for terabit DSL

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***Abstract*— We investigate the propagation of terahertz radiation on a complex multi-element metal wire waveguide ensheathed in a metal jacket. Mode mixing due to bends and nonuniformities along the waveguide axis result in a nearly random mode pattern at the output. This stochastic mixing is ideal for a vectored transmission, analogous to the multiple-input, multiple-output (MIMO) concept commonly used in wireless networking, and could enable terabit-per-second data rates on the existing cables already in use by DSL systems.**

I. INTRODUCTION

As the consumer demand for higher data rates increases, new cost-effective technologies will be required to meet this demand. One possible solution is to integrate THz carrier waves with the copper wires already in use by plain old telephone service (POTS) [1]. Such cables are typically equipped with a number of twisted pairs of copper wire, surrounded by a metal sheath which serves as shielding. These structures are ubiquitous, and may be able to efficiently guide THz waves. Straight single-wire [2,3] and two-wire [4] structures have been used as THz waveguides. However, the idea of using twisted, bent, and non-uniform wires for wave guiding has not yet been explored in the THz range.

Here, we investigate the output spatial modes of a two-wire waveguide that incorporates a bend and an external metal sheath. The sheath serves to confine the propagating energy, capturing radiatively lost energy and redirecting it back onto the wires. This also facilitates mode mixing, resulting in a complicated mode pattern at the waveguide output. Such a mode pattern leads to higher order mode loss as the waveguide is extended. We characterize the output mode patterns for all possible input excitation spots. Furthermore, the attenuation resulting from the higher order modes present in the waveguide is measured and caculated.

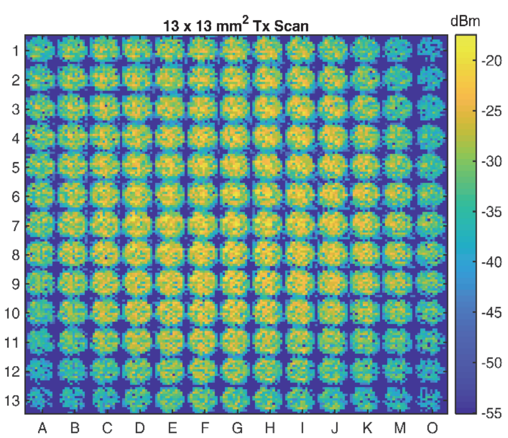

Fig. 1. A display of 169 measured 13x13mm^2 images of the waveguide output mode for all possible input excitation positions.

II. RESULTS

Fig. 1 shows the recorded spatial profiles at the output of the waveguide, for all 169 possible positions of the input beam spot, at 200 GHz. These results show the dependence of the received signal's spatial mode on the input signal's position. They indicate a complex mode mixing, which creates a channel with high diversity for data transfer. Fig. 2 illustrates one particular pattern, measured at the waveguide output when the input excitation is exactly centered between the two wires. Even though this is the most symmetric possible input excitation location, the mode mixing nevertheless results in a complicated output mode, with approximately 9 'hot spots' at which a significant amount of energy is focused. The mixing of modes generate the hot-spots and additionally contribute to the loss present in the waveguide.

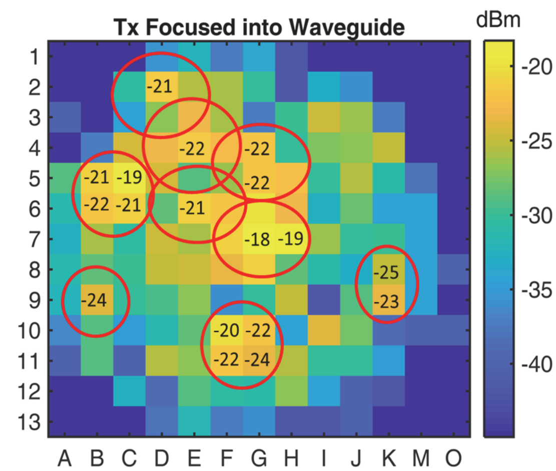

Fig. 2. The spatial pattern at the output of the waveguide, when the input Tx is focused into the center. Several 'hot spots' are observed (red circle).

In order to characterize the attenuation of the beam contributed by the two wire waveguide and the metal sheath, the waveguide length is increased to lengths of 30cm, 65cm, 100cm, 140cm and the integrated power is measured at the receiver. The attenuation due to the two wire waveguide was found to be 1.97dB/m, consistent with prior data [4]. However, the attenuation due to the metal sheath is found to be nonlinearly decreasing as a function of waveguide length. This nonlinear behavior is explained by calculations made for the attenuation per meter of individual modes, comprised primarily of higher order modes (Fig.3). As the signal propagates through the waveguide, it will consist of a superposition of modes of various orders, and will experience the total attenuation equal to the cumulative loss for the individual modes. The ohmic loss for the first 14 modes in the sheath is calculated at 200 GHz, for each of the lengths of the metal sheath, and summed to attain the overall attenuation of the beam as a function of the length of the sheath [5,6]. From the total attenuation, the integrated power is calculated and we show it resembles the measured behavior (Fig.4). Further confirming the primary source of loss in this waveguide to be attributed to the higher order mode loss due to the metal sheath.

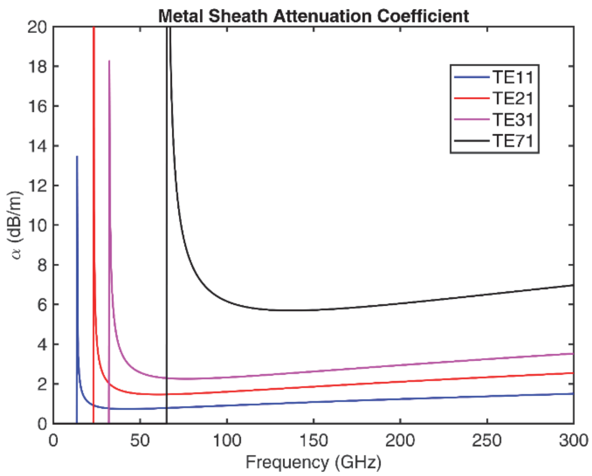

Fig. 3. Attenuation per length calculation for the lowest order modes (TE11, TE21) and some higher order modes (TE31, TE71) loss present in the metal sheath as a function of the operating frequency.

With this data, we can now characterize the correlations among these patterns, as a first step towards identifying specific channels that can be used in a vectored transmission for independent and simultaneous data transfer. This could lead to a boost in data rates provided by wireline services, by exploiting the already-installed cables at much higher frequencies than those that are currently used in DSL systems.

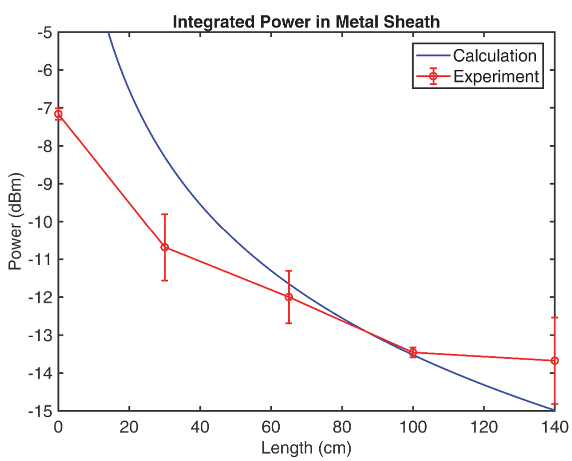

Fig. 4. The total integrated power calculated for the superposition of the first 14 modes present in the metal sheath compared to the experimental results.

III. Summary

These measurements, which use only two wires contained in a metal sheath, are the first step towards demonstrating the feasibility of a DSL wire line with terabit-per-second data rate. We have shown the spatial diversity created by mode mixing and the ohmic loss due to the aforementioned modes contribute to the nonlinear attenuation of the signal as the waveguide length increases. Future steps include the addition of multiple twisted pairs, as well as a study of the extra losses introduced by dielectric insulation. These losses are likely to be the limiting factor in the range and data rate for these transmission systems.

References

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