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COMPUTATIONAL INVESTIGATIONS OF THZ TRANSMITTANCE IN THE ATMOSPHERE

Xingyu Yang[1], Casey Calhoun[1], and Ronald Calhoun[2]

[1]BASIS Scottsdale, Scottsdale, AZ 85259
[2]Arizona State University, Tempe, AZ 85281

ABSTRACT

With the recent scientific advancements in Terahertz (THz) wave propagation and reception technology, there has been significant development in new possibilities for using THz waves – offering new possibilities in THz detection and ranging. A first foundational step toward this goal is to better understand THz transmittance in the turbulent atmosphere. In this project, a frequency modulation pattern of THz waves was created by utilizing a system of shifting frequency based on temperature, air humidity, and distance of transmission. The total path loss of the wave in air, based on the wave spread and molecular absorption, was then modeled using radiative transfer theory, onto a set of JavaHAWK filtered-HITRAN data representative of an air sample. This data was used to generate a path loss matrix, which was then used to optimize frequency of transmission for the specific conditions. The concept to be evaluated is whether adaptive frequency modulated THz might usefully decrease transmission losses by adjusting to atmospheric conditions (such as local variations in temperature and humidity).

I. INTRODUCTION

One significant challenge to the development of terahertz detection and ranging is the high level of molecular absorption associated with these frequencies **[1]**. The presence of water vapor in the atmosphere provides a particularly significant contribution to this absorption, with potential path losses of up to 10 dB **[2]**. To avoid this path loss, the THz band is divided into smaller usable segments of approximately 10-100 GHz, windows which are found and characterized by modeling the path loss, or reduction in power density of the molecule **[2]**.

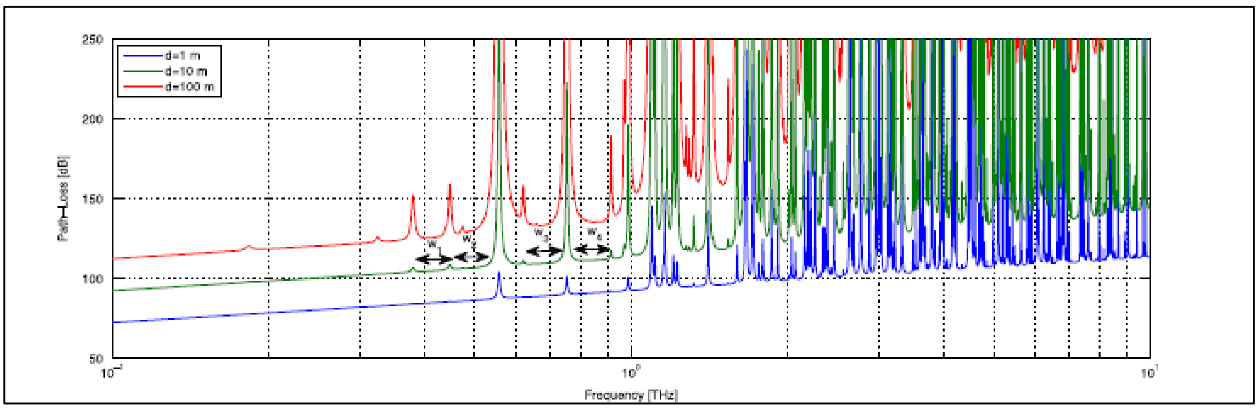

Figure 1 - Path Loss in THz Band for Different Transmission Distances
(Image credit to Kurner)

The purpose of this project is to characterize the path loss in THz atmospheric transmission by taking into consideration the spreading loss and the molecular absorption loss based on conditions such as air temperature, air humidity, and transmission distance, and then minimize this level of path loss in order to create better possibilities for detection and ranging applications.

A path loss matrix for a given ambient temperature, humidity level, and transmission distance, was determined for variables of frequency and distance. The data extrapolated from this matrix allows for the optimization of a frequency band to minimize path loss. The project uses the gas properties of oxygen and H2O based on data extrapolated from JavaHAWK(JAVA). The code is then used to investigate the aspects that affect the total path loss.

II. METHODOLOGY

In order to minimize the amount of wave attenuation, the highest sources of path loss in a sample of air were characterized, and key factors affecting this amount of path loss were identified. Using the properties of THz waves, it was found that, in a sample of air, absorption by water molecules created the highest source of path loss. Thus, the unique characterizing factor of path loss was found to be the molecular absorption coefficient (units of M/cm-1), also known as the molecular attenuation coefficient. This coefficient was modeled, and found to depend on variable factors such as the pressure, temperature, humidity of the environment, and properties of transmission of EM wave such as distance of transmission, and, especially, the frequency of the THz wave transmitted. Thus, it was established that if the optimal frequency for a certain ambient factors could be determined, that the amount of path loss could be minimized, which would result in minimal power input for the device.

We used a line-by-line model to simulate the various cases of molecular absorption based on path loss, generating a power matrix of total path loss with variables of distance and frequency. From this matrix, the ideal frequency can be extrapolated. Our envisioned design for use of this modulation scheme consists of a transmitter that changes frequency transmission rate based on perceived factors of ambient temperature, pressure, and humidity, and detected distance of transmission to reduce the path loss of the signal.

HITRAN (high resolution transmission), source of molecular information used, is a database that contains the parameters necessary simulate atmospheric molecular transmission and radiance from the microwave through ultraviolet region of the spectrum. This database is available online, for free, upon request. JavaHAWK is an open source software included with the database that performs simple functions on the information, such as filtering by wavelength. Since HITRAN, itself, contains a distribution of isotopologues - isotope molecule - of a certain gas g, the software JavaHAWK (JAVA HITRAN ATMOSPHERIC WORKSTATION) is used to filter and compile the molecules of resonance within the Terahertz range, specifically within air. In the line-by-line model, the total path loss was found by referencing the parameters of each isotopologue within the JavaHAWK filtered HITRAN data, and finding the sum of the path loss. To create a frequency-optimization modulation design for a THz model, a power matrix was generated, detailing the total path loss in dB for a specific set of atmospheric conditions, using a model for the amount of attenuation of the molecule.

This was created by using radiative transfer theory, and the Beer-Lambert law to model the molecule's properties of absorbance - the amount of the EM wave absorbed by the molecule - and spreading - the free-space loss due to the attenuation of molecules moving through a medium. The variable medium absorbance is found as the sum of the individual medium absorbance coefficients of each individual isotopologue. For a gas, its own molecular absorbance coefficient is found by taking the weighted sums of the isotopologues its isotopologues. Within the HITRAN database, for each gas type (i.e. - H2O, O2, etc.), there is a distribution of isotopologues that models the actual distribution of each in a random sample of that gas. Thus, taking into consideration the percentage of that gas, the total molecular absorption coefficient can be found by simply taking the sum of the individual molecular absorption coefficients.

III. RESULTS

We created a path loss matrix for atmospheric conditions of 1 atm and 298 K; the distribution of this matrix is represented in Figure 2. In this figure, the 'windows' of H2O absorption can be seen in dark red, indicating sections of absorbance that result in significant power loss. This allows us to determine the frequency ranges that should be avoided.

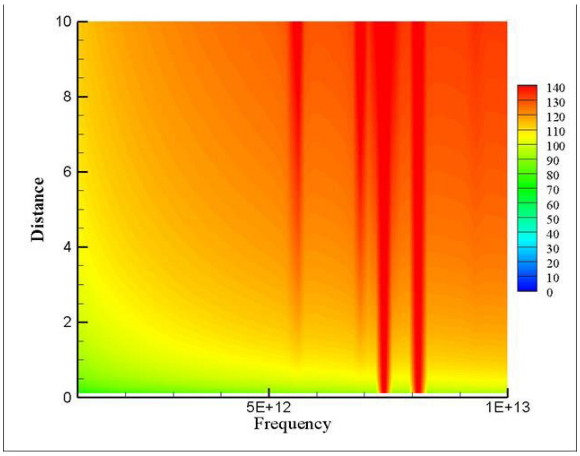

Figure 2 - A color-intensity distribution found for sample power matrix
Image Credit to Authors

IV. CONCLUSION

We developed a method of finding the optimal THz frequency for a certain set of parameters within a short transmittance distance by creating and optimizing a power matrix.. The information contained in this power matrix can help shape future designs of THz detection and ranging devices by directing the specific frequencies at which power loss is minimized **[3]**. Future research should investigate the application of this power matrix to specific devices, and how they will minimize path loss based on these specific conditions. In addition, this can be applied, specifically, to LIDAR detections systems within the THz range to allow for optimization of frequency and power **[4]**, **[5]**.

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