Infrared Free Space Communication
The autonomous testing of free space infrared communication

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I - Introduction and Motivation

Fiber optics has been a winning player in the game of high-speed communication and data transfer in cable connections. Yet, in free space RF has been the repeated choice of communication medium of the space industry. Investigating the benefits of free space optical communication over radio frequency is worthwhile. An increase in science data rate return capabilities could occur if optical communication is implemented. Optical communication systems also provide efficiencies in power, mass, and volume over RF systems[1]. Optical communication systems have been demonstrated from a satellite in orbit with the moon to earth, and resulted in the highest data rates ever seen through space (622Mbps)[2]. Because of these benefits, optical communication is far superior to RF.

The HiDRA (High Data Rate Architecture) project is researching Passive Misalignment Mitigation of Dynamic Free Apace Optical Communication Links. The goal of this effort is to enable gigabit per second transmission of data in short range dynamic links (less than 100 meters). In practice this would enhance data rates between sites on the International Space Station with minimal size, weight, and power requirements. This paper will focus on an autonomous code and a hardware setup that will be used to fulfill the next step in the research being conducted. The free space optical communications pointing downfalls will be investigated. This was achieved by creating 5 python programs and a top-level code to automate this test.

II – Automated Testing Methodology to Determine Misalignment Effects

A laboratory set up was created to transmit an infrared data beam over a distance of 20 meters. This is used to model the travel distance of the communications link on the ISS. The 20 meter link simulated the distance between the EXPRESS Logistics Carrier and the main cabin of the ISS where the technology would be implemented. The nodes at the main cabin and the Expedite the Processing of Experiments to the Space Station (EXPRESS) Logistics Carrier move relative to each other and this causes misalignment in the system. An Anritsu BERTwave was used to characterize the received data from the IR Optical link as the misalignment conditions that could be seen on the ISS were simulated. The lab set up hardware included a transmitter and receiver board, linear and angular motors (KDC101) to change the transmission misalignment, a BERTwave to send continuous

pseudorandom data and obtain bit error rate measurements, and an Aardvark to read the I2C power data from the receiver board.

This setup is shown below in Figure 1.
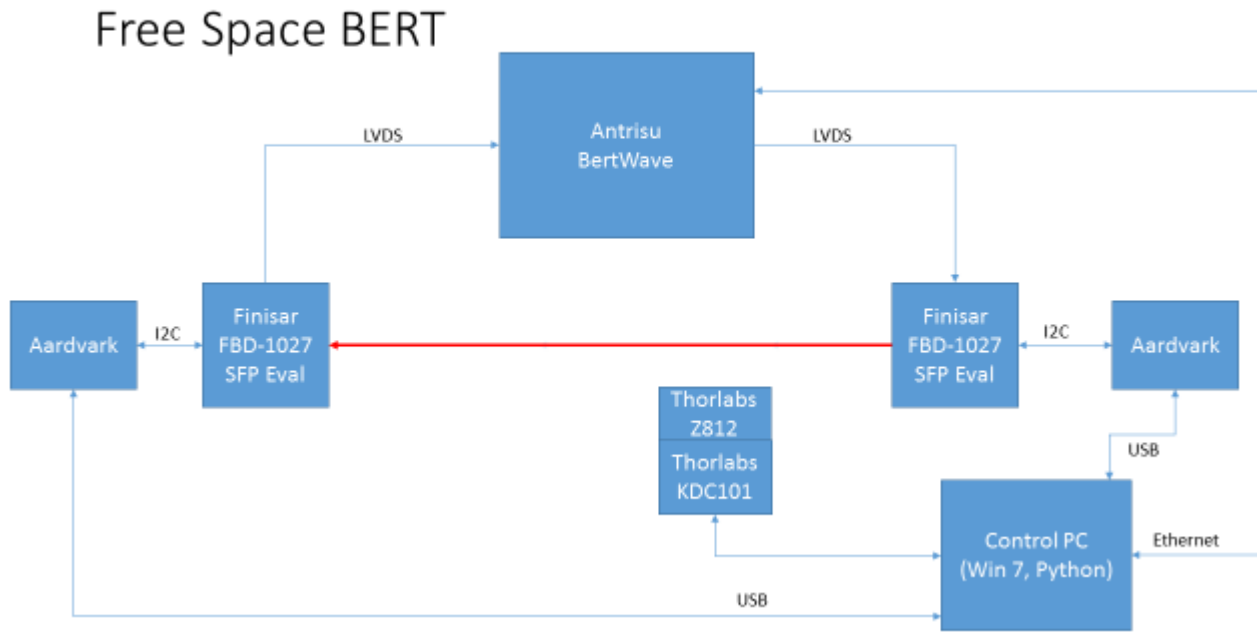
Figure 1, Lab Setup for Experiment

Table 1, Lab Hardware Description

| Thorlabs KDC 101	A motor controller that can interface with multiple types of mechanical movement modules and programed to exicute various movement commands.
Anritsu BERTwave	A bit error rate measuring device, sends a pseudorandom set of data at a given speed and reads the number of bit errors that occur.
Aardvark	A device to read I2C off of the Finisar board, data is in Hexadecimal and is converted to a float to read of the dBm power received and sent.
FBD-1027	A circuit board that transmits the free space optical data laser and receives data. The board interfaces with the aardvark and BERTwave to take measurements on the data being sent.

An automated testing program was created for the purpose of taking analytical data and repeated tests. The automated function of the test will enable obtaining much more accurate data than compared to data taken by hand. This is due to the ability to accurately move the motors for misalignment and take repeated power and bit error rate measurements. Implementing a fully automated test will also reduce operation time of the test greatly compared to human interface with the devices. Another added benefit of an automated code to implement the experiment is that it can be modified slightly to be applied to similar test setups. The test code was created as follows: A program was created to interface with a motor controller to move the motor by a specific amount. This enabled the ability to change the angle and lateral position of the transmitter. Code was created to manipulate I2C

data from an Aardvark into power dB values, which enabled obtaining the power of the received signal. A control code was designed to control functions of a BERTwave error detector in a way that allowed the program to run until a specific confidence level of the bit error rate was achieved.

Table 2, Control Software Module Description

| Motor Controller Code	This code interfaces with KDC Motors and moves them a specified distance dependent on a value obtained from the TopLevelCode. Also it performs operations on the motor such as homing to the 0 position. This code returns the end position of the move operated to the top level code.
Aardvark Program	This code interfaces with Aardvark Hardware and read hexadecimal values. It then converts these values into receive and transmit power of the free space optical link. This code returns the transmit power and receive power to the top level code.
BERTwave Program	This code interfaces with the BERTwave and runs the data across the optical link until a specific confidence level is reached. It returns the bit error rate and the confidence level of the measurement achieved.
TopLevelCode	This code interface and controls operation of all other codes. It prints experimental data to a comma separated file and makes decisions on control of the codes dependent on the returned values.

For the purpose of running automated tests, all of these programs are encompassed in a top level misalignment code that called each of these programs to run in the following operation: Move the angle of transmission to boar sight, take the power received in dBm at the current location, move the motor in the positive direction until a 0.5 dB change in receive power occurs, run the BERTwave data acquisition program and send data until a bit error rate received is at a 95% confidence level, take the power in dBm received at this new location for hysteresis correction (redundancy), and move the motor again. This program continues to run until the maximum angle before loss of signal occurs, then the program continues the same operation but moves the motor in the negative direction until loss of signal occurs, the program then runs back past its original position. Data is recorded continuously and printed to a CSV file. The operation of the code is shown below in figure 2.
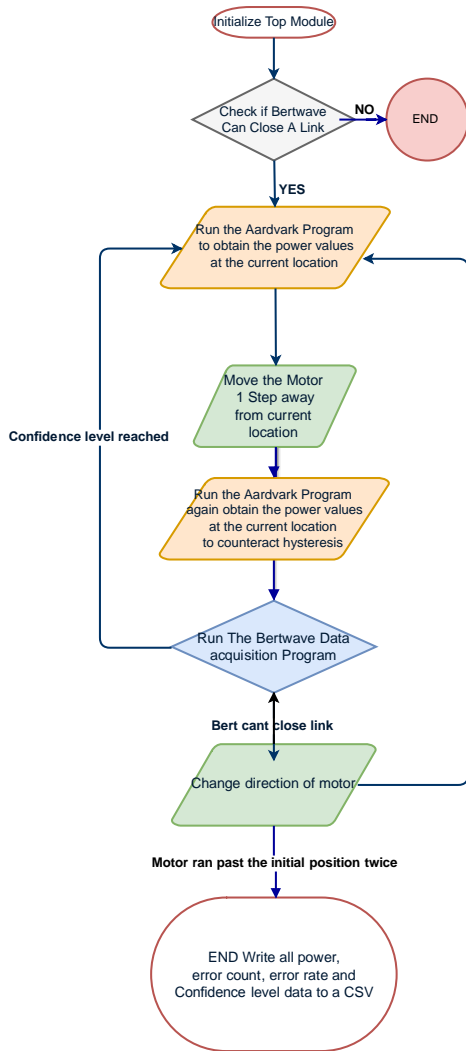
Figure 2, Top-level Code operation

The BERTwave Data Acquisition program was used to obtain the bit error rate data for each position of the motor. The code was imported to the top-level code and run for each position as shown above. The code functioned as follows: The BERTwave would send data for a short period and read the error count to determine if the link can be closed. If the link is closed, then the BERTwave begins a testing measurement. The BERTwave runs for a second and then reads back the bit error rate, the total number of errors that occurred, and the total number of data bits sent. The program uses the confidence level equation for the error free case if no errors have occurred on the first iteration, or if there has not been a change in the number of errors reported from the previous iteration. If an error does occur, the error case confidence level equation is used. If the confidence level calculated reaches or passes the user defined confidence level, then the program ends and the bit error rate and the confidence level of the data is reported. If the confidence level is lower than the confidence the user requested, the BERTwave would run another second and

then follow the above operation. The code will iterate until the requested confidence level is met. This operation is shown in figure 3 below.
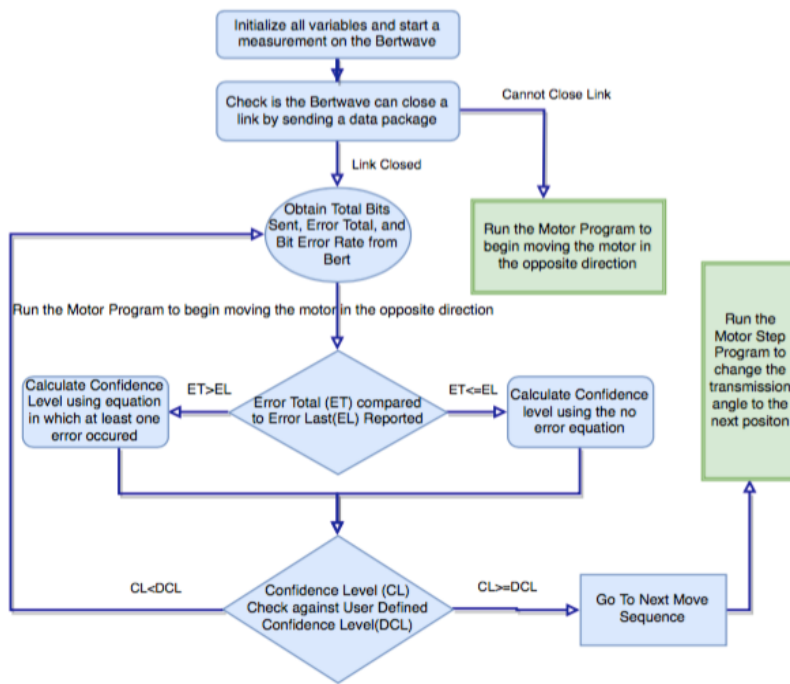
Figure 3. BERTwave Data Acquisition Program which is run by the Top-level Code

A Poisson distribution was used to determine the confidence level of the current BERTwave measurement. This was done to insure that the reported bit error rate was a statistically sound measurement. Data was taken every second. This runtime between measurements was decided upon because data was being sent at a rate of 10 gigabytes per second. This is a sufficient time to send enough data to get good reported values and limit latency of the code's operation. The user is able to set a specific confidence level for the BERTwave bit error rate code. The code will run until this confidence level is achieved. The equations used to calculate the confidence of the bit error rate measurement are shown below in Equations 1 and 2.

The following equation was used in the case where no error had occurred respect to the last reported data[3].

$$C_l = 1 - e^{-B_s * BER} \tag{1}$$

The equation below was used when errors occurred in the last reported data[4].

$$C_l = \left(1 - \left(e^{-B_s*BER} * \frac{1}{B_e!} * \left(BER * B_s{}^{B_e}\right)\right)\right)$$
(2)

Where C_l = Confidence Level, B_s = Number of bits sent, BER = Bit Error Rate, and B_e = Number of bits in error.

After the confidence level is reached, the motor is moved until a user settable change in power is observed. Then, the code repeats and runs the BERTwave until the confidence level is reached again. This approach was chosen over moving a predefined distance to ensure enough data points are collected to show a trend of power received vs bit error rate as the relationship between distance traveled and power is nonlinear.

III-Results

The data is stored in a comma separated variable file as shown below. It can be seen that the relationship between the angle of transmission and power received is nonlinear. As the angle increased or decreased from boar sight, the power decayed exponentially. This can be seen in Figure 4. It can also be seen that the relationship between receive power and bit error rate is related. Figure 5 below shows the power vs bit error rate relationship for a test run of the automated misalignment program. There is hysteresis in the motor. This is due to inaccuracies in the KDC101 movements. The given commands did not result in the motor moving to the exact position requested. Changes in the true positions were seen to be dependent on the direction of approach of the motor.
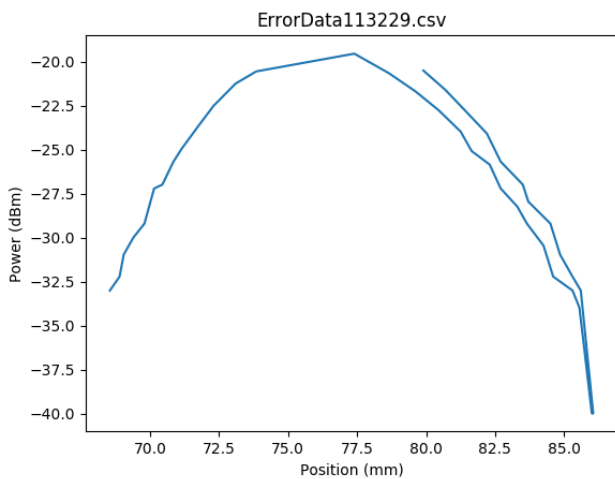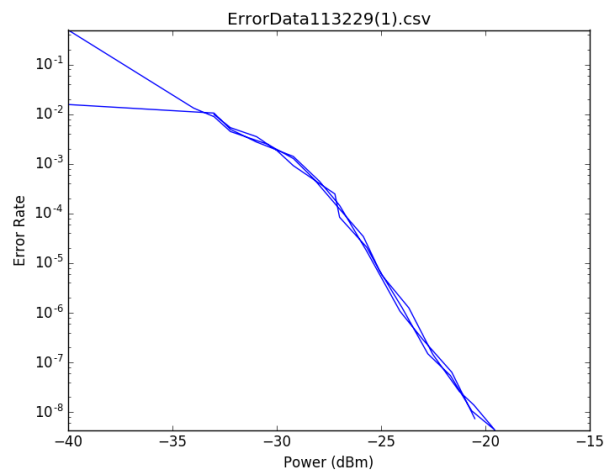

Figure 4, Position vs. Power

Figure 5, Error Rate vs. Power

IV-Future Work and Conclusion

Multiple tests were implemented to measure the performance of free space communications links using infrared light. The tests were created using Python language and integrated with hardware devices.

This first test was created for the HiDRA project within NASA's Space Communication and Navigation program. Its purpose was to determine the relationship between the angle of transmission of a beam, the power received, and the bit error rate of the signal.

The next step in this development will be to add a programmable attenuator to characterize the infrared data beam to baseline transceiver performance in a fiber only system for comparison to the free space measurements.

Acknowledgments

References

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