Linewidth Enhancement Factor Measurement for Radio over Fiber Simulation over Multimode Optical Fiber

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LATÉCOÈRE

Project Motivation

Right now, aircraft primarily use flexible steel cables and coax cables for control systems; however, the data demand of these systems is increasing exponentially. Optical communication systems utilize light, transmitted over fiber-optic cables, to deliver signals between computers and offer many advantages over electrical systems, such as low power consumption and high data transfer rates.

Single-mode fiber (SMF) is well-characterized but transmits only a single signal and is sensitive to vibration and thermal instability, so **multimode fiber** (MMF) would be more advantageous. We set out to characterize a SMF signal with a physical testbench that can determine linewidth, or a way to quantify the received signal's power and quality.

With the results of this project, we intend to determine the respective qualities of both SMF and MMF signals and determine whether MMF is appropriate for aircraft applications.

Requirements and Background

Our intended deliverables are as follows:

- Measurement of the **linewidth** of the electrical signal produced by the photodiode in the constructed optical system. The linewidth is defined as the **full width at half maximum** (FWHM) of the spectrum in the frequency domain.
- Modeling of the **transfer function** for our setup. This mathematical function relates the electrical signal produced by the system to the optical power of the laser source. The function was constructed through research from academic papers and textbooks and was modeled in MATLAB.
- Design and construction of the physical testbench for calculation of the laser linewidth using results inferred from the transfer function model and the observed electrical signal. Modern optical communication systems demand a narrow linewidth laser to increase data transfer rates.
- Results and comments on the SMF system characteristics, and a discussion of the implications to MMF transmission.

When a semiconductor laser is operating normally, two kinds of photon emission events are possible within the laser cavity:

- **Spontaneous emission** occurs when an electron-hole pair combine spontaneously to produce a photon.
- **Stimulated emission** occurs when a photon assists in the recombination. The new photon produced is in-phase with the original.

Stimulated emission produces coherent (has the same phase) light, but photons from spontaneous emission are rarely in phase, creating both **phase** and **intensity noise**. Phase noise contributes heavily to the linewidth of the signal, while random intensity noise creates ripples and bumps in the frequency domain.

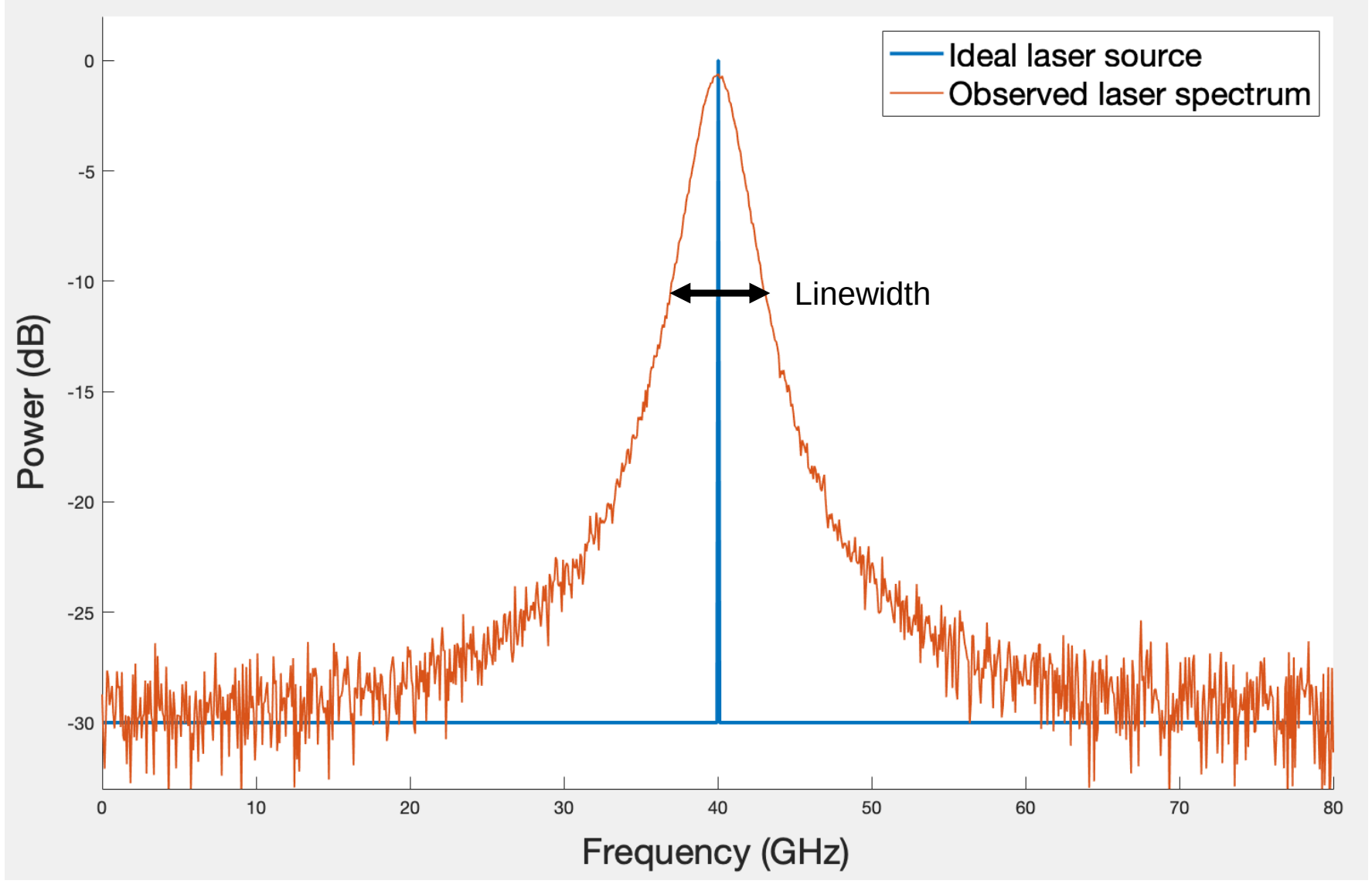


Figure 1. Example of ideal (blue) and realistic (orange) laser spectrums.

Physical Testbench Implementation

It was concluded from the researched literature and modelled transfer function that the linewidth of the laser could be measured via a **self-heterodyne** ("self-mixing") technique. The laser beam is split in two paths. One path is modulated by an EOM, while the other is sent over a long delay line, in a **Mach-Zehnder interferometer** (MZI) configuration. This configuration was the best self-heterodyne method for our goals, given its low cost and high accuracy.

- The delay arm uses a 1 km fiber delay to decorrelate the two halves of the split signal. The length of the delay arm is required to exceed the coherence length of the input signal. The chosen delay will do so for all inputs with a linewidth over 100 kHz.
- The modulation arm uses an **electro-optic modulator** (EOM) to perform double-sideband suppressed-carrier modulation and a polarization controller to ensure the light entering the EOM is polarized correctly.
- Following the delay and modulation, the output of the two arms is recombined into a beat note that contains phase noise related to the original signal.

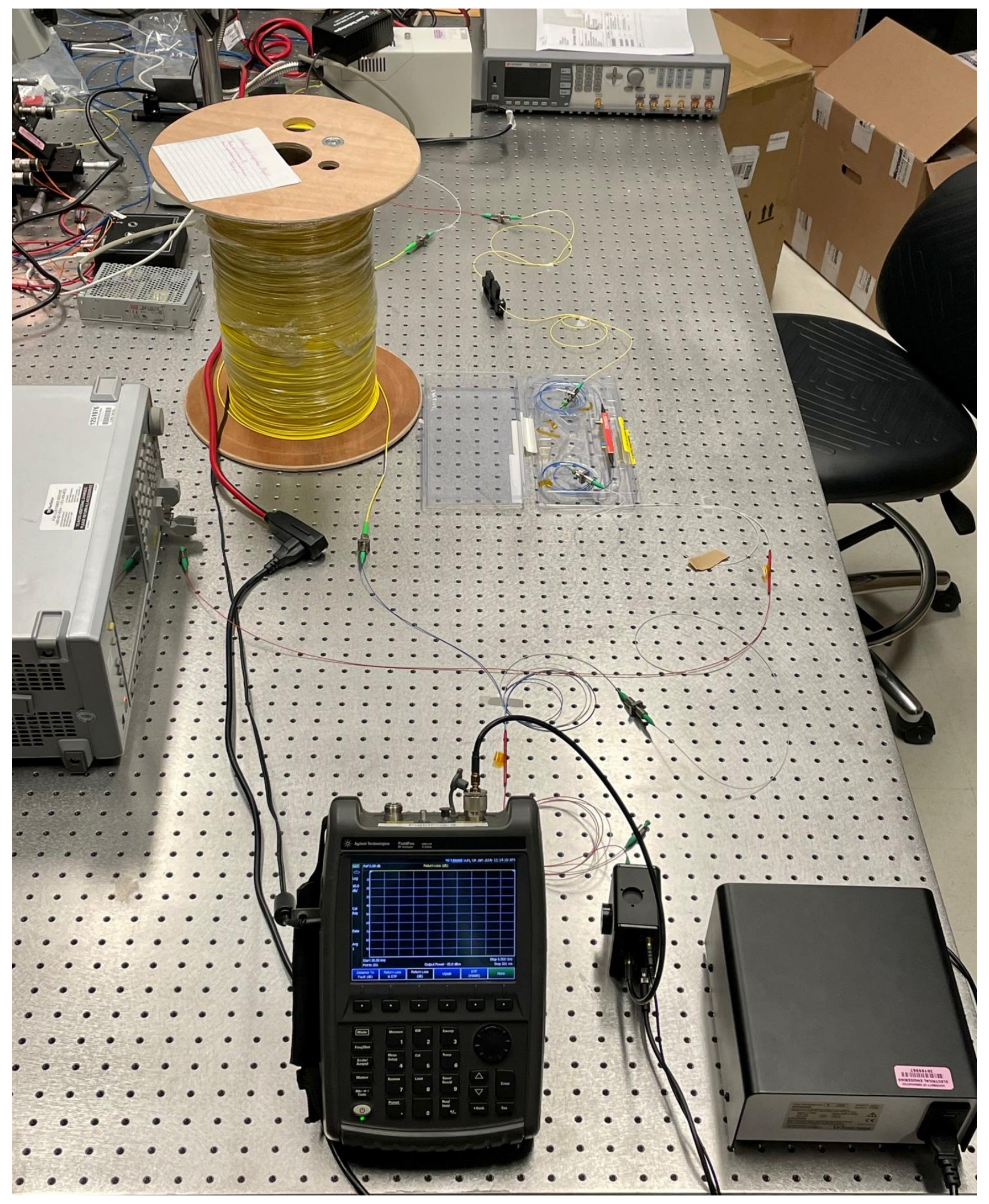


Figure 4. Our final assembled Mach-Zehnder testbench.

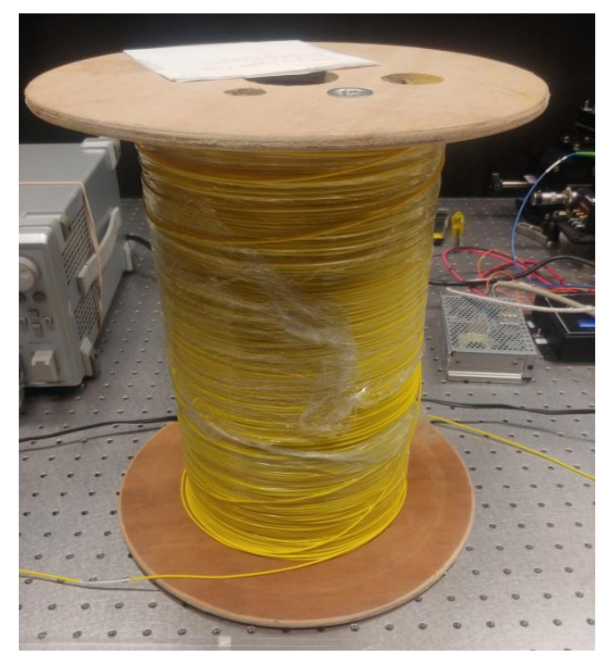


Figure 2. The delay arm.

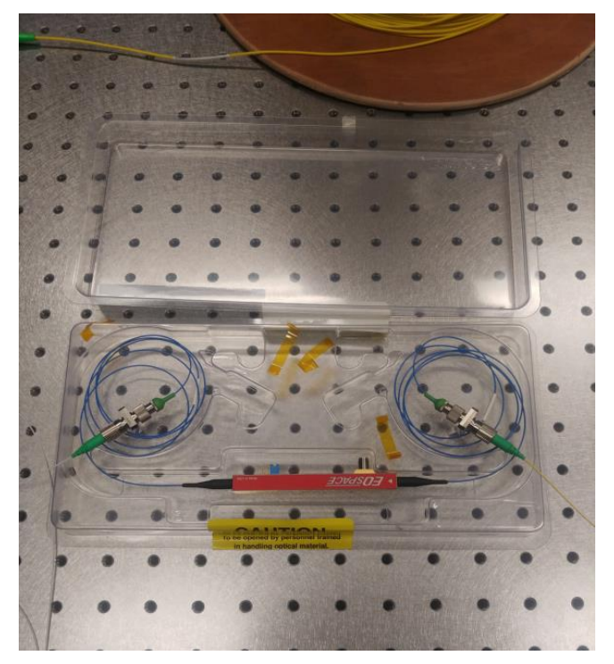
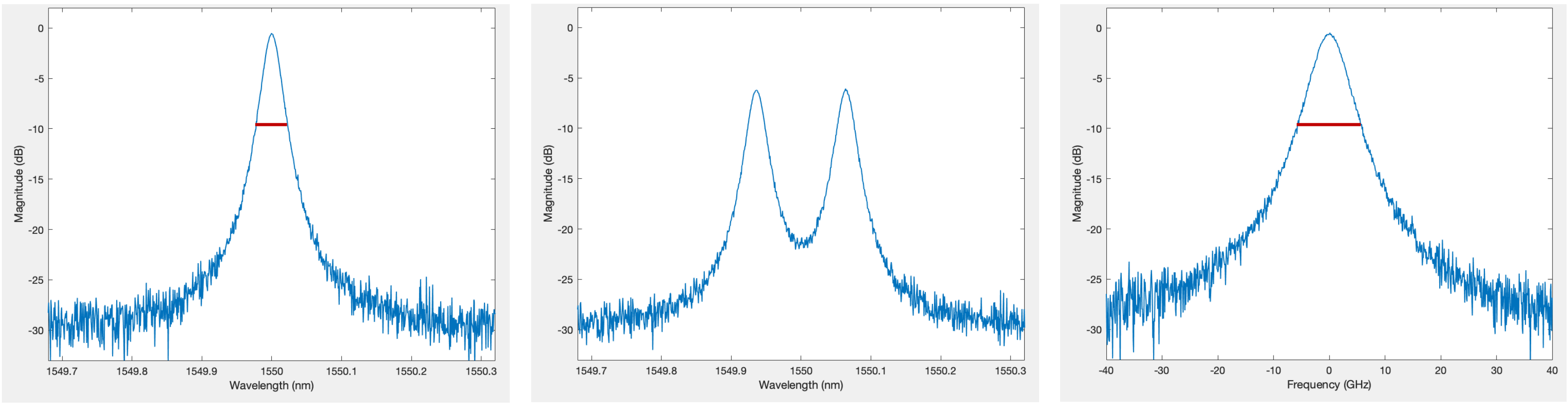


Figure 3. The EOM.

Signal Analysis

The laser signal can be simply represented by the laser beam's **power spectral density** (PSD), which is the power spectrum as a function of frequency. When the signal is modulated, sidebands are created around the center frequency at distance equal to the frequency of modulation. As the signals combine during "self-mixing," interference causes a beat frequency at the photodiode, and the PSD of this electrical signal has the same shape as the laser signal.



a.) Signal from laser (optical)

b.) Signal after modulation

c.) Photodiode signal (electrical)

Figure 5. Example plots of the initial laser signal (a), the signal after modulation by the EOM (b), and the resulting electrical photodiode signal (c). Linewidths (FWHM) of (a) and (c) are shown in red.

Experiment and Results

In order to extract the laser linewidth, the team drew from research articles and scientific literature to design an interferometry system that would meet our requirements. Figure 6 depicts a diagram of this selected optical system.

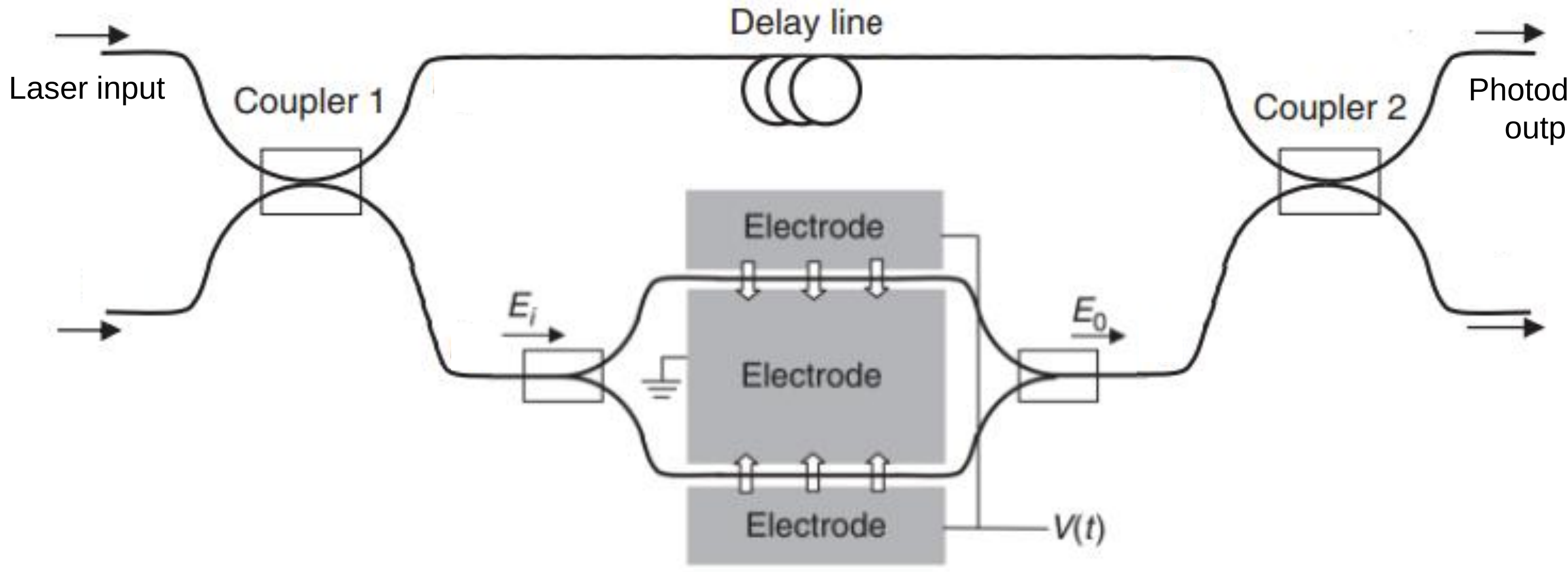


Figure 6. Diagram of the optical system. The configuration is an EOM and delay line, in respective parallel arms of a Mach-Zehnder interferometer. The input signal is provided by a tunable laser, and the output optical signal is converted to electrical via a high frequency photodiode, then monitored with a network analyzer.

To conduct the experiment, we begin by applying the desired RF signal to the EOM and monitoring the optical output directly with an **optical spectrum analyzer** (OSA). The OSA gives the spectral density of the signal, but the resolution is too low to determine the linewidth accurately. Instead, the OSA is monitored while the DC bias to the EOM is varied, until the carrier (center) frequency is effectively suppressed (see Figure 5.b), and the two sidebands are easily distinguishable. Next, the photodiode is connected to one of the output coupler's arms. The signal produced is a power signal equal to the sum of power signals in either arm of the MZI. The frequency domain of the electrical signal produced is observed with a high frequency **electrical spectrum analyzer** (ESA). The linewidth of this photocurrent signal has been calculated and reported in recent literature to be equal to *twice the linewidth of the laser source.*

Future Work, References, and Acknowledgments

Future teams will finish the characterization of the MMF signal and make a final determination of its quality, and efficacy in aircraft.

To make that determination, the team would build an MMF version of the Mach-Zehnder testbench, and a transfer function that described the system. They would then analyze the resultant data with the linewidth from the transfer function and be able to make that determination.

Stretch goals would be to test the MMF system under circumstances similar to what it would have to tolerate in aircraft applications.

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