# ABSOLUTE DISTANCE MEASUREMENT BY DUAL COMPACT AND SIMPLE DESIGNED MODE-LOCKED FIBER LASERS

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**Abstract**:

Dual-comb based absolute distance measurement techniques, are attractive because they can scan an entire range window quickly, and requiring no balancing of interferometer paths. We describe a gold coated glass cover plate based dual compact and repetition rate difference tunable free running fiber laser comb based LIDAR (light detection and ranging) system. One end of the laser cavity is butt-coupled with a cover glass plate that coated with 35 nanometers of gold as out coupler, and the other is with a SAM for the mode-locking and high reflection. The difference in repetition rate is tuned to ~1 kHz by a tunable optical delay, providing an experimental update rate of only ~1 ms. The lasers were housed in a box with dimension of 32 cm × 28 cm × 9.5 cm to protect them from air currents and robust handling, but no temperature control or active feedback was used to otherwise stabilize their output. The probe comb is retro-reflected off a pc connector and a movable corner cube to form the measurement path. The measurement precision is 10 μm at the minimum acquisition time of 1 ms, and dropping 400 nm at 400 ms averaging periods from the Allan deviation for the target-to-reference distance at 1.09 m and continuous averaging times up to 0.8 s. The high update rates and 2 m-long ambiguity ranges make this system potentially useful for manufacturing or machining applications where absolute distance measurement is needed.

**Keywords**: Distance measurement, Fiber laser, Mode-locked

## 1. INTRODUCTION

Precise absolute distance measurement is very crucial for large-scale manufacturing. Classic multi-wavelength interferometry can be slow and subject to cyclic errors. Dual-comb based techniques, a subclass of the cross-correlation techniques [1], are particularly attractive because they can scan an entire range window quickly allowing for rapid update rates against multiple targets, and requiring no balancing of interferometer paths. Previously, we utilized the gold coated fiber as the output coupler. However, the larger longitudinal spacing in the coating machine for the fiber end with the connector is required. Here, we describe a gold coated glass cover plate based dual compact and repetition rate difference tunable free running fiber laser comb based LIDAR (light detection and ranging) system. The pulse time-of-flight yields a precision of 0.4 μm with non-ambiguity range of 2.1 m in 0.4 s for distance of 1.09 m.

## 2. EXPERIMENTAL SETUP

### *2.1 Laser design*

The experimental set up is depicted in Fig. 1. Two lasers employed here is an Erbium all fiber design operating at repetition rates of 70 MHz, which corresponds to the time of flight non-ambiguity range of 2.1 m. The cavity design is a semiconductor saturable absorber mirror (SAM) based linear-cavity modeled loosely on [2] (see Fig. 1). Each end facet of the fiber cavity is connectorized with a pc connector. One end of the laser cavity is formed by sandwiching a SAM between the pc connector at the fiber end and a second pc connector, which is known as the butt-coupled technique. The output coupler at the other end of the laser cavity is similarly formed by another pc connector, which butt-coupled with a cover glass plate that coated with 35 nanometers of gold. The gold coated facet is directly connected to the pc connector of the cavity end. It is sufficient to monitor the repetition rate of only a single laser for the self-calibrating data analysis technique in the ranging applications. Therefore, we designed two output port. One output port is through the gold reflector (Out 1), and the other is from the PBS rejection channel through the WDM (Out 2). An intracavity polarizer simultaneously provides the polarization selectivity and an input channel for the 1480 nm pump light. The gain is provided by a 31 cm section of highly doped (80 dB/m) Er fiber with 8 □m core diameter. One of the lasers employed a tunable optical delay for the cavity length adjustment and resulted in the repetition rate difference tunable from 0 Hz to 500 kHz for the asynchronous sampling.

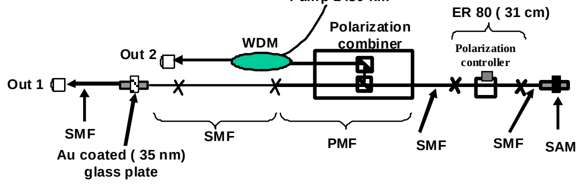


Fig. 1: Design for the fiber laser. SMF-single mode fiber, PMF - polarization maintaining fiber, SAM- saturable absorber mirror.

The difference in repetition rate is tuned to ~1 kHz, providing an experimental update rate of only ~1 ms. Both repetition rates are not stabilized by any controller and just roughly measured by frequency counters. The lasers were housed in a box as shown in Fig. 2 with dimension of 32 cm × 28 cm × 9.5 cm to protect them from air currents and robust handling, but no temperature control or active feedback was used to otherwise stabilize their output.


Fig. 2: Real picture of the housing for the dual mode-locked fiber lasers.

### *2.2 Laser performance*

The laser is started lasing with pumping laser diode (LD) current ~100 mA. As the pumping current tuned up to 200 mA, the fiber laser is started to mode-lock. After fine tuning the polarization controller, the output power is increased up to 12 mW as the pumping increased to 370 mA as shown in Fig. 3. It is possible to increase the average power up to ~300 mW level by further power amplification. However, in the glass plate end output coupler port, the power is increased to ~ 0.5 mW. This port is good for supporting the high reflectivity port but not suitable for the output port. The 0.2 mm thickness of the glass plate will decrease the coupling efficiency because the typical design for the adapter is just for two fiber coupler without any material in the center.

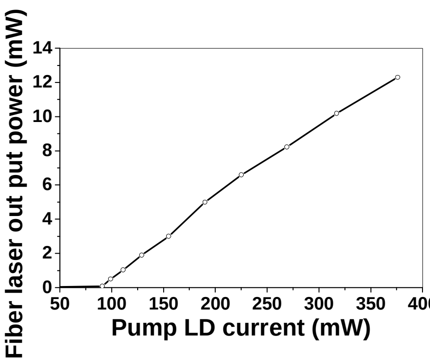


Fig. 3: Power scaling of the rejection port (Out 2) of the simple mode-lock fiber laser as increasing the pumping current of the laser diode.

The stable radio frequency (RF) spectrum with a fundamental frequency of ~70 MHz is acquired from the detector that impinged by the output of gold reflector as shown in Fig. 4. It can be used for the monitor port of the repetition rate through RF frequency counter by further filtering and amplifier during the absolute distance measurement applications.

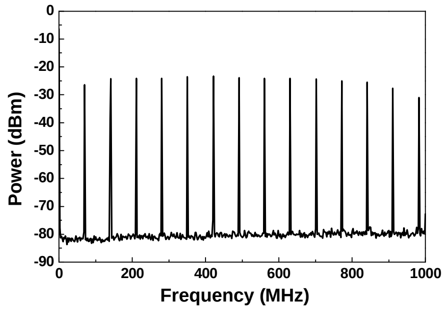


Fig. 4: RF spectrum of the 70 MHz mode-locked fiber lasers.

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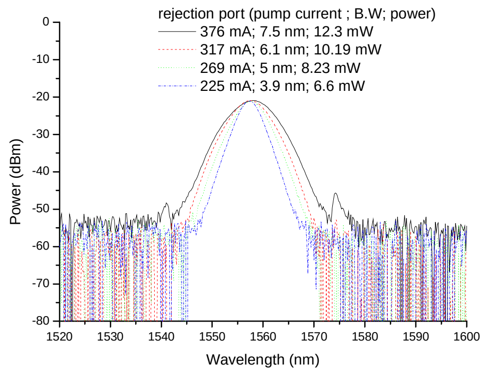
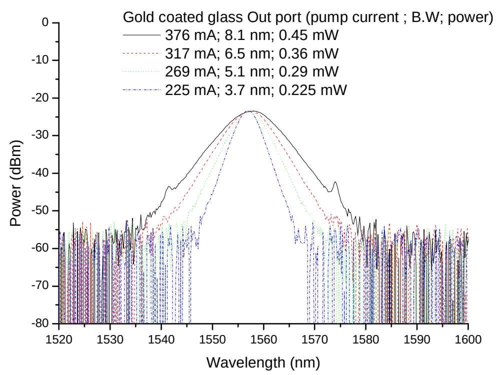



(a)




(b)

Fig. 5: The output optical spectrum from (a) rejection port and (b) gold coated glass plate coupler for four different pumping current. The FWHM bandwidth and the output power are also indicated.

The evolution of optical spectrum with respect to the laser diode (LD) pumping current is shown in Fig. 5. The center wavelength is ~ 1560 nm and FWHM (full width half max) is increased from 3 nm to 8 nm as the current increased to ~375 mA. The spectrums at the end of the cavity and the medium (i.e. PBS port) are a little different but similar. One is increased from 3.9 nm to 7.5 nm, the other from 3.7 nm to 8.1 nm. It could be attributed from the different soliton mode in different position of the fiber cavity. Besides, the bandwidth is higher in the case of PBS rejection port than the end coupler port as pumping current lower than 269 mA. As the pumping current increased, the bandwidth is increased slower than the other. This is typically the soliton effect in the cavity as the obvious side peak happened in the high pumping power of both cases. It is possible to fabricate the high average power femtosecond laser by further power amplification and dispersion compensation for many applications such as supercontinuum generation.

### *2.3 Absolute distance measurement*

The absolute distance measurement uses these two ultrafast fiber lasers in a time-domain down-sampling configuration as shown in Fig. 6. The probe comb is retro-reflected off a pc connector and a movable corner cube to form the measurement path. The overlap between the two reflected probe pulses and local oscillator (LO) pulses is digitized synchronously with the LO comb pulses and stored for analysis.

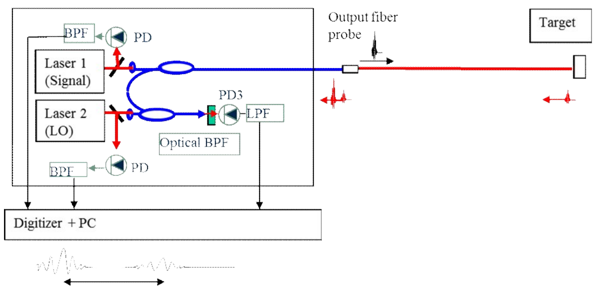



Fig. 6: Schematic diagram of the system setup.

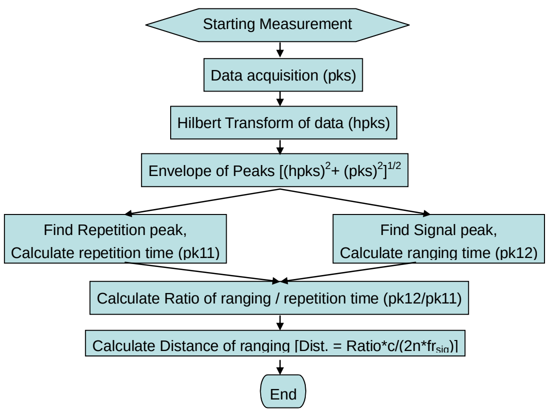



Fig. 7: Flow chart for the data analysis

The analyzing procedure is shown in Fig. 7. The raw data is Hilbert transformed to generate the imaginary component of the complex analytic representation of the signal from the real part. The carrier oscillations can then be removed by taking the modulus of this complex analytical signal to leave only the modulus, or signal envelope. The different pulses are then fit with a series of Gaussians to find the peak centers across the interferogram. For these well-behaved spectra, a Gaussian fit was well matched to the observed shape. We identify a target and reference reflection and, for each interferogram, calculate the time delay between the target and reference pulse (pk11) and the time delay between subsequent reference pulses (pk12) both in units of the pulse sample number. The distance is calculated as shown in the flow chart of Fig. 7.

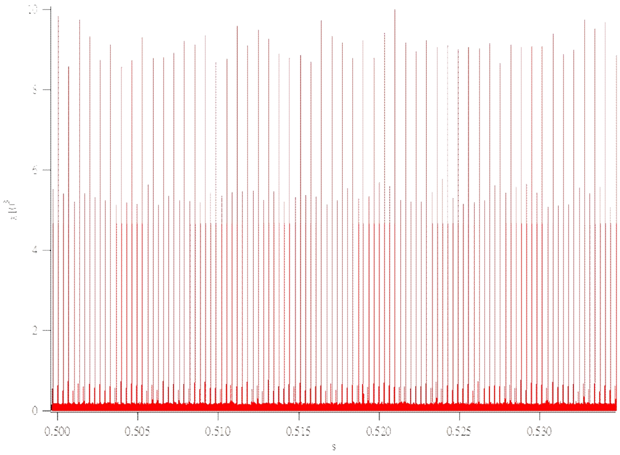



Fig. 8: The calculated envelop for the distance measurement of 1.09 m.

The envelope of peaks for the distance measurement of 1.09 m is depicted in Fig. 8. From the program analysis, the average distance of ~1.09117 m is depicted in Fig. 9. The Allan deviation is shown in Fig. 10.

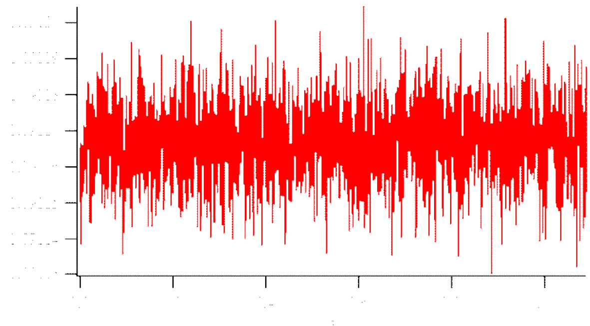


Fig. 9: The calculated distance data from the program analysis. The vertical axis unit is meter.

From the Allan deviation for the target-to-reference distance at 1.09 m and continuous averaging times up to 0.8 s, the measurement precision is 10 μm at the minimum acquisition time of 1 ms, (set by the 1 kHz difference in laser repetition rates) and dropping 400 nm at 400 ms averaging periods.

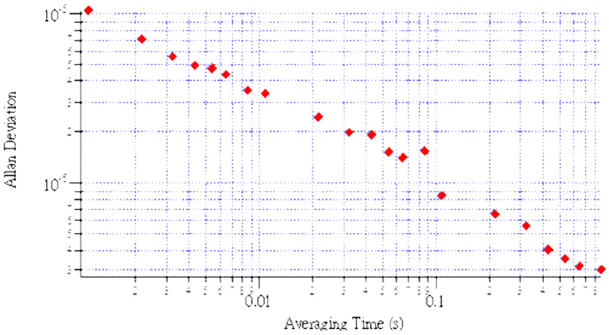



Fig. 10: Measurement precision (Allan deviation) at a reference to the target range of 1.09 m.

## 3. CONCLUSIONS

We had utilized a gold coated glass cover plate to establish dual compact and repetition rate difference tunable free running fiber laser comb based LIDAR system. The pulse time-of-flight yields a precision of 400 nm with non-ambiguity range of 2.1 m in 400 ms for distance of 1.09 m. The 1 kHz high update rates and long non-ambiguity ranges make this system potentially useful for manufacturing or machining applications.

## REFERENCES

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