Method for Increasing the Operating Distance of MEMS LIDAR beyond Brownian Noise Limitation

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Abstract: A LIDAR based on a MEMS tunable VCSEL uses resonance tuning to increase the maximum range ten-fold. A novel demodulator reduces the peak electrical beat frequency from 52GHz to 235MHz for compatibility with standard CMOS.
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1. Introduction

Present implementations of FMCW LIDARs are too large and costly to meet the requirements of consumer applications such as gaming. MEMS-tunable semiconductor lasers [1] heterogeneously integrated with electronics and Si-photonics [2] overcome these limitations but suffer from elevated phase noise due to Brownian motion induced (BMI) displacement of the MEMS mirror used for tuning [3]. The noise effectively limits the maximum operating range of the LIDAR and increases the uncertainty of the range measurement.

The solution presented here overcomes both problems by operating the tunable laser at the resonant frequency [4] of the MEMS mirror, thereby greatly increasing the modulation rate which translates into higher signal amplitude with correspondingly improved signal-to-noise ratio, increasing the maximum range from a fraction of a meter to 9 meters, sufficient for many consumer and industrial applications. This approach differs from and can be optionally combined with phase noise reduction techniques [5,6] for even greater performance.

Without special measures, increasing the modulation rate in the prototype results in a beat frequency of 52GHz at a range of 10m and would be difficult to demodulate with low power electronics. A cascade MZI is used in the receiver to reduce this frequency to 235MHz, well within the range of standard CMOS technology.

2. Effect of high rate frequency modulation

Conventional FMCW LIDAR operation principle is shown in Fig. 1.

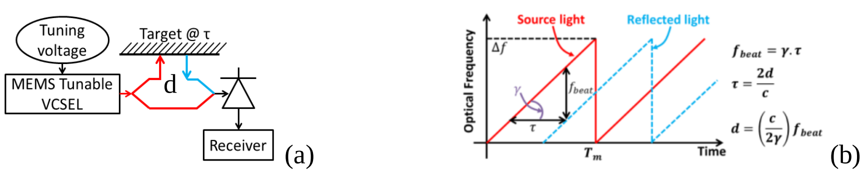


Figure 1. Linear FMCW LIDAR principle of operation. a) System block diagram; b) Graphic representation.

In MEMS tunable VCSEL Brownian motion adds a random component to the cavity length, resulting in phase noise and limiting the maximum measurement range of the LIDAR. For accurate triangular frequency modulation the mirror is operated at a much smaller frequency than mechanical resonance. The amount of noise on the beat frequency depends both on the amplitude and frequency of the Brownian motion. Since Brownian motion of a MEMS structure is mostly concentrated around its resonance frequency, even small BMI-displacement amplitude (a few Pico meter noise on the wavelength) can have a devastating effect on the ranging measurement.

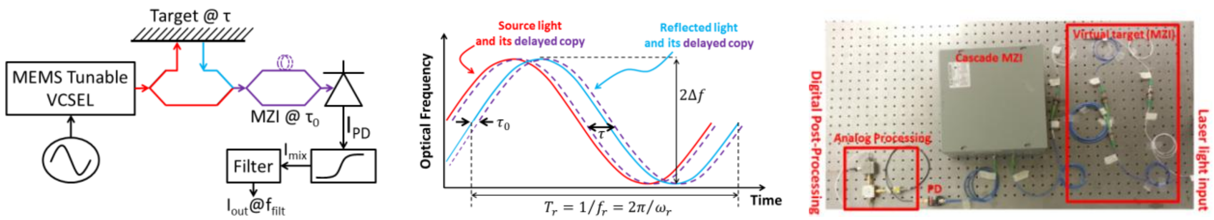
The effect of the Brownian noise can be reduced by increasing the ramp rate γ. Sinusoidal tuning at the mechanical resonant frequency results in the highest achievable rate with low tuning voltage, helped both by the increased frequency and, in an underdamped environment, the mechanical Q-factor of the MEMS mirror.

3. Frequency demodulation and ranging

If we tune the laser at resonance, for the architecture of Fig. 1a, the beat frequency will be:

$$|f_{beat}| = \omega_r.\tau.(\Delta f/2)|\cos(\omega_r t)| \quad (1)$$

where ω_r is the MEMS resonance frequency, Δf is the modulation depth and τ is the round-trip delay to the target. For a resonance frequency of 200kHz, a modulation depth of 10nm, and a target at 10m ($\tau = 67ns$), the maximum beat frequency can go as high as 52GHz presenting a significant challenge for the photodiode and electronic demodulator. Fig. 2 shows the proposed LIDAR architecture using a cascade MZI to solve this problem.



(a) (b) (c)

Figure 2. Proposed system operation. a) Architecture; b) Graphic representation; c) Measurement setup.

From Fig. 2b the beat frequencies of each of the source and reflected signals (solid lines) with their corresponding delayed versions (dashed lines) are given:

$$\left|f_{beat,source}\right| = \omega_r.\tau_0.(\Delta f/2)|\cos(\omega_r t)| \qquad (2)$$

$$\left|f_{beat,reflect}\right| = \omega_r.\tau_0.(\Delta f/2)|cos(\omega_r(t-\tau))| \qquad (3)$$

While τ in equation (1) is the round-trip delay to the target and can go as high as 67 ns for a target at 10m, τ_0 in equations (2) and (3) is a value of our choice and can be as low as 300ps bringing down the maximum beat frequency from 52GHz for the architecture of Fig. 1a to 235MHz for the proposed architecture.

Then, in the nonlinear electronic block, that includes a symmetric RF splitter followed by a mixer to square its small signal input, these two signals are mixed and only the low frequency part of the result goes through the filter:

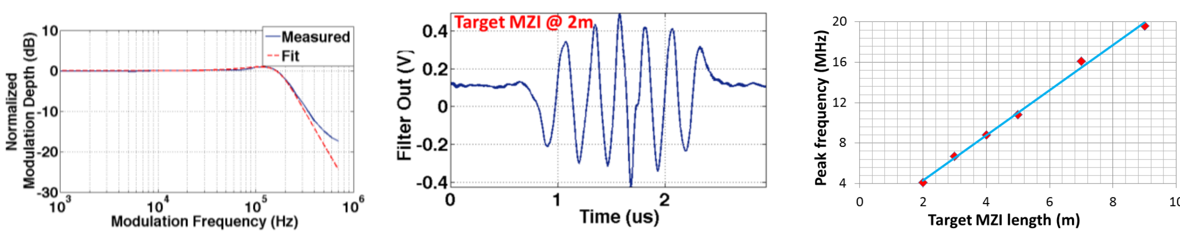
$$\left|f_{filt}\right| = \omega_r{}^2.\tau.\tau_0.\Delta f|sin(\omega_r t)| \qquad (4)$$

If we choose $\tau_0 = 300ps$, this frequency can be as low as 20MHz for a target at 10m.

4. Results

Straightforward triangular modulation at a frequency 100 times slower than the MEMS resonance results in a range measurement severely degraded by phase noise and maximum range of less than 50cm. The proposed technique improves the maximum in-fiber round-trip range 10-fold to 9m.

Fig. 3 shows the measurement results. Fig. 3a is the small signal tuning frequency response of a sample VCSEL. Fig. 3b is the measured beat signal for a MZI length of 2m acting as our target. Equation (4) shows that the range information (i.e. round-trip delay) is linearly encoded in the amplitude of the frequency of the beat signal. This fact is verified by the measured results presented in Fig. 3c.



(a) (b) (c)

Figure 3. Measurement Results. a) Tuning frequency response; b) Filter output in Fig. 2a; c) Peak beat frequency versus MZI length.

5. Conclusions

We have demonstrated increasing the maximum measurement range of a LIDAR using a MEMS tunable VCSEL from a few tens of centimeters to about 9 meters (in-fiber) using sinusoidal tuning at the mechanical resonance of the laser and an optical demodulation technique for reducing the maximum electrical beat signal frequency, for a target at 10m distance, from 52GHz for conventional systems to 235MHz.

6. Acknowledgments

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7. References

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