Regards,
Eric Funk, Ph. D.
Partner, Red Mountain Radio LLC
eric@redmountainradio.com
970-325-2158 ×12

Random Modulation CW Laser Radar with Heterodyne Detection and Phase Noise Cancellation

Eric E. Funk
Naval Research Laboratory
Code 5652
4555 Overlook Ave., SW
Washington, DC 20375
202-404-5420

Mark Bashkansky
Naval Research Laboratory
Code 5614
4555 Overlook Ave., SW
Washington, DC 20375
202-767-2512

ABSTRACT

We present a new 1550-nm pseudorandom modulated continuous wave laser radar architecture with heterodyne detection. Phase noise cancellation using sub-carrier multiplexing is demonstrated. Furthermore, a combination of electrical and optical delay is used to obtain an offset in the pseudorandom modulation code as required for correlation.

Random Modulation CW Laser Radar with Heterodyne Detection and Phase Noise Cancellation

Eric E. Funk
Naval Research Laboratory
Code 5652
4555 Overlook Ave., SW
Washington, DC 20375
202-404-5420

Mark Bashkansky
Naval Research Laboratory
Code 5614
4555 Overlook Ave., SW
Washington, DC 20375
202-767-2512

In this paper we outline the development of a range-finding laser radar architecture designed to operate with readily available telecommunications components in the 1550nm “eye-safe” region.

Range finding can be performed with either pulsed or modulated CW waveforms. This includes pseudorandom modulated CW (RM-CW) waveforms [1]. RM-CW waveforms have been considered for direct detection laser radar [2]. However, heterodyne detection is advantageous for increased sensitivity. Heterodyne detection usually implies stringent requirements on laser line-width. But this requirement can be relaxed if a microwave sub-carrier and optical phase noise cancellation circuitry [3-4] are employed.

Our heterodyne RM-CW architecture is illustrated in Figure 1. In the transmitter, light from a CW DFB laser is intensity modulated with a microwave tone at a frequency of $f_{rf\text{-}t}$= 5 GHz. A 27.32 Mb/s, 2^{12}-1 bit-long maximal length pseudo random bit sequence (*M*-sequence) is applied to the bias port of the Mach-Zehnder modulator (MZM). The amplitude and offset of the *M*-sequence is adjusted such that the modulator’s bias shifts between $V_\pi/2$ and $3V_\pi/2$ when a bit changes state. The slope of modulator’s transfer function is equal in magnitude but opposite in phase at these two points; hence, by switching between these two bias conditions, bipolar phase shift keying (BPSK) is performed on the microwave sub-carrier [5]. In order to simulate the delay and attenuation of free space propagation, the transmitter output is then sent through 0.7 km of single mode fiber, attenuated, and the polarization change is compensated.

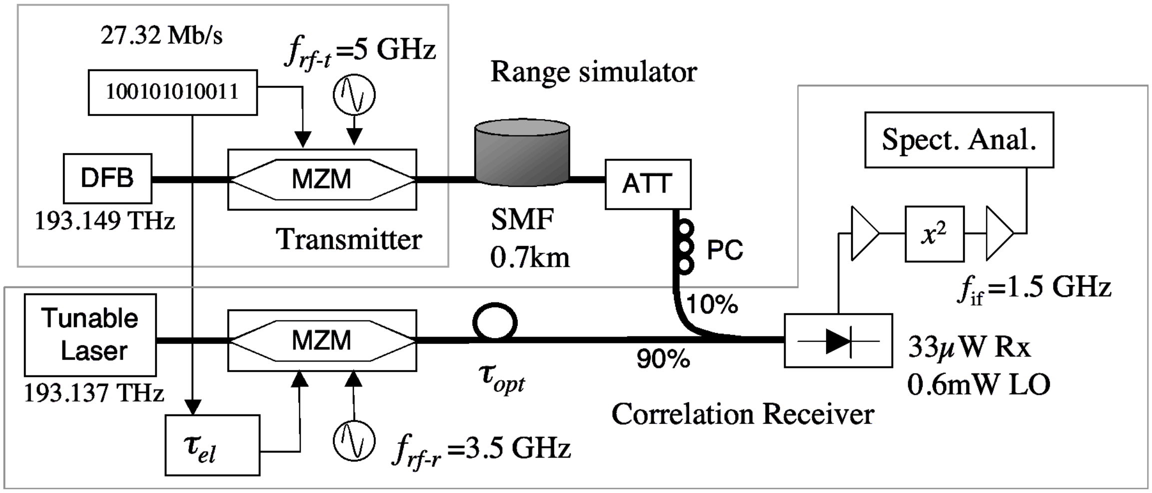

Figure1. Setup of random modulation CW laser radar test-bed. Symbols are explained in text.

The laser radar receiver uses a tunable laser as a local oscillator (LO). The frequency of the LO laser is set to be approximately 12 GHz lower than the transmitter. This laser is externally modulated with a microwave tone at a frequency of f_{rf-r}= 3.5 GHz. A time-delayed replica of the transmitted *M*-sequence is applied to the bias port of the receiver's MZM. As in the transmitter, the drive level is adjusted to produce BPSK modulation of the microwave sub-carrier. The modulated LO signal is then combined with the received signal in a 10% coupler.

The signal detected at the photodiode includes a beat frequency of $f_b \approx 12$ GHz, corresponding to the offset between the transmitter and receiver optical frequencies; however, as expected, this signal is spectrally broadened due to the DFB laser's optical phase noise. In addition, sidebands are present at $f_b \pm f_{rf-t}$ and $f_b \pm f_{rf-r}$. These sidebands correspond to the microwave sub-carriers used in the transmitter and receiver respectively. Since the *relative* spacing of the sidebands is fixed, we can send this signal into a microwave square law detector in order to cancel the optical phase noise [4] and recover stable carriers at the following difference frequencies: f_{rf-t}, f_{rf-r}, and $f_{rf-t} - f_{rf-r}$.

The signal at $f_{if} = f_{rf-t} - f_{rf-r}$ = 1.5 GHz is of particular interest. This intermediate frequency (IF) signal results from the modulated transmitter and receiver *M*-sequences being multiplied together. Since the sequence that we use in the receiver is a time shifted replica of the transmitted sequence, the magnitude of the IF signal will correspond to the autocorrelation function of the *M*-sequence. Hence, the measured IF signal magnitude will be maximized when the relative delay between the transmitted and received *M*-sequences is zero. Note, the relative delay can be adjusted by changing either the electrical delay, τ_{el}, or the optical delay, τ_{opt}. This provides a straightforward means of measuring range between transmitter and receiver.

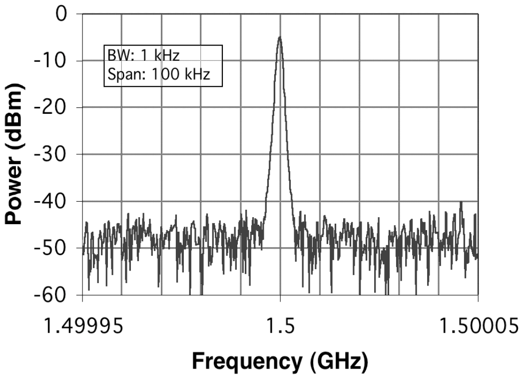

Figure 2. Received/correlated intermediate frequency signal with optical phase noise cancelled.

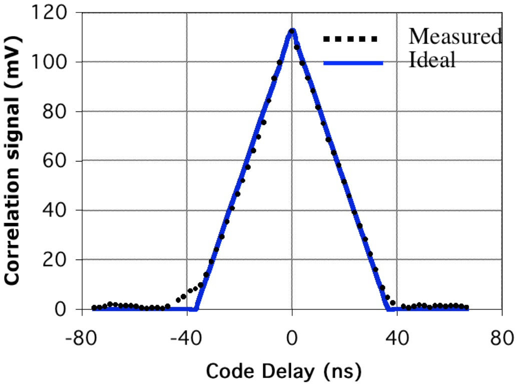

Figure 3. Correlation Function. Measured: magnitude of 1.5 GHz IF signal vs. relative code delay. Ideal: Autocorrelation function of *M*-sequence.

The system was tested using the configuration described above. Our IF signal measured at the square law detector (with no relative transmitter/receiver code delay) is shown in Figure 2. Even though a DFB laser with large phase noise was used, observe that the signal line-width was narrow. The optical phase noise was cancelled. Also, the SNR exceeded 35 dB with 1 kHz of detection bandwidth. Furthermore, as the relative time delay between the transmitter and receiver codes was changed, the carrier amplitude decreased according to the autocorrelation function of the *M*-sequence. This was verified by plotting the signal amplitude vs. code offset and comparing to the ideal autocorrelation function of the *M*-sequence. As shown in Figure 3, there is excellent agreement between theory and measurement. A code delay of zero corresponds to the condition where the transmitter-to-receiver path length delay is exactly equal to the sum of τ_{el} and τ_{opt}.

In this demonstration, the received power level (measured at the photodiode input) was 33 μW. Nevertheless, sensitivity could be improved by replacing the square law detector used here with an optimally filtered product detector [4].

This architecture offers a number of unique features. First, since the RM signal is applied to both the transmitter and receiver through an MZM, it is possible to use a combination of optical and electrical delay in order to produce the required transmitter-receiver code offset. Adjustable optical delays, τ_{opt}, could be obtained with a switched optical delay line [6]. The optical delay would be particularly useful when nondeterministic RM signals are used, since such signals cannot be replicated.

Furthermore, since our RM signal is imposed on a microwave sub-carrier, the receiver is designed to be sensitive to the sub-carrier phase rather than the optical phase. Hence, a simple square law detector cancels the optical phase noise. However, if filters are used before the square law or product detector, they must exhibit sufficient bandwidth to account for the laser line-width.

In conclusion, with the architecture demonstrated here, a direct detection RM laser radar system could be constructed with off-the-shelf 1550-nm telecommunications components. While the RM signal allows us to obtain range information from a modulated CW signal, optical phase noise cancellation circuitry allows us to cancel DFB laser phase noise. Furthermore, heterodyne detection allows us to overcome limited photodiode sensitivity. Finally, since the RM signal is modulated onto the receiver's LO laser, the required code offset can be generated by a combination of electrical and optical delay. Next, the system will be field tested with a hard target after the addition of an erbium doped fiber amplifier to the output port.

REFERENCES

[1] Merrill I. Skolnik, *Radar Handbook*, New York: McGraw Hill, Ch. 20.5, 1970.

[2] N. Takeuchi, N. Sugimoto, H. Baba, and K. Sakurai, ''Random modulation of cw lidar,'' *Appl. Opt.* vol. 22, pp.1382–1386, May 1983.

[3] Toshiaki Kuri, and Ken-ichi Kitayama, "Optical heterodyne detection of millimeter-wave-band radio-on-fiber signals with a remote dual-mode local light source," *IEEE Trans. Microwave Theory and Tech.*, vol. 49, pp. 2025-2029 Nov. 2001.

[4] Richard Gross, Robert Olshansky, and Mark Schmidt, "Coherent SCM-system using DFB lasers and a phase noise cancellation circuit," *Photon. Technol. Lett.*, vol. 2, pp. 66-68, Jan. 1990.

[5] W. D. Jemison, A. J. Kreuzberger, and E. Funk, "Microwave Photonic Vector Modulator for High-Speed Wireless Digital Communications," *IEEE Microwave Wireless Compon. Lett.*, vol. 12, pp. 125-127, Apr. 2002.

[6]A. P. Goutzoulis, D. K. Davies, and J. M. Zomp, "Prototype binary fiber optic delay line," *Opt. Eng.,* vol. 28, pp. 1193-1202 1989.