

OptiSystem applications: LIDAR systems design

10 February 2017 (Version 1.0)



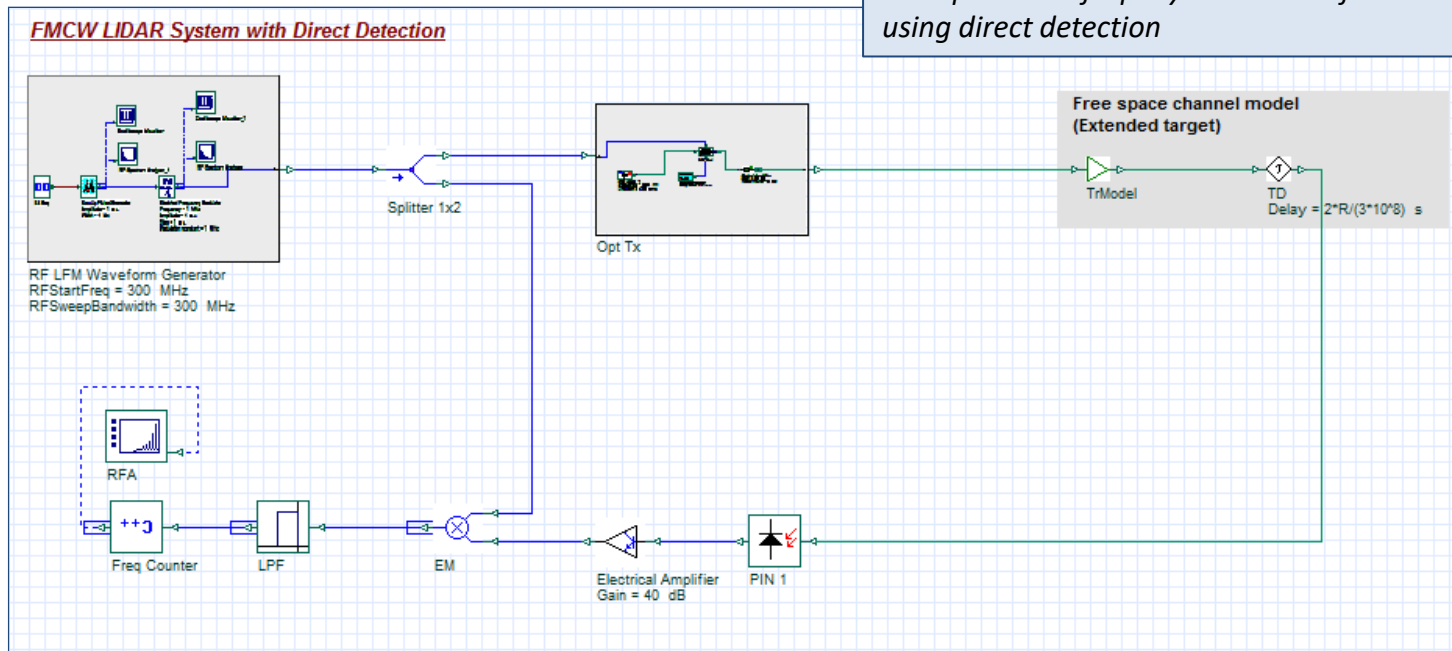
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- The following four example designs demonstrate how to simulate light detection and ranging systems (LIDAR) using OptiSystem, specifically:
 - Laser pulse time of flight range measurement
 - Phase-shift range measurement
 - Frequency Modulation Continuous Wave (FMCW) range measurement with direct detection
 - FMCW range measurement with coherent detection
- The reference project for this application note is: *LIDAR system designs Version 1_0.osd*.

Example view of OptiSystem model for FMCW LIDAR using direct detection



Range measurement (Time of flight) (1)

- Using laser pulses, the time of flight range measurement method measures the time it takes for a transmitted pulse to travel from the transmit device to the target and back to the receiver. The range is then calculated from [1]

$$R = \frac{\text{TimeofFlight} \cdot c}{2}$$

where c is the speed of light.

- The received signal power is determined based on an extended target model and is calculated as follows [2]

$$P_r = P_t \frac{\rho D^2 (\tau_{opt}) (\tau_{atm})^2}{4R^2}$$

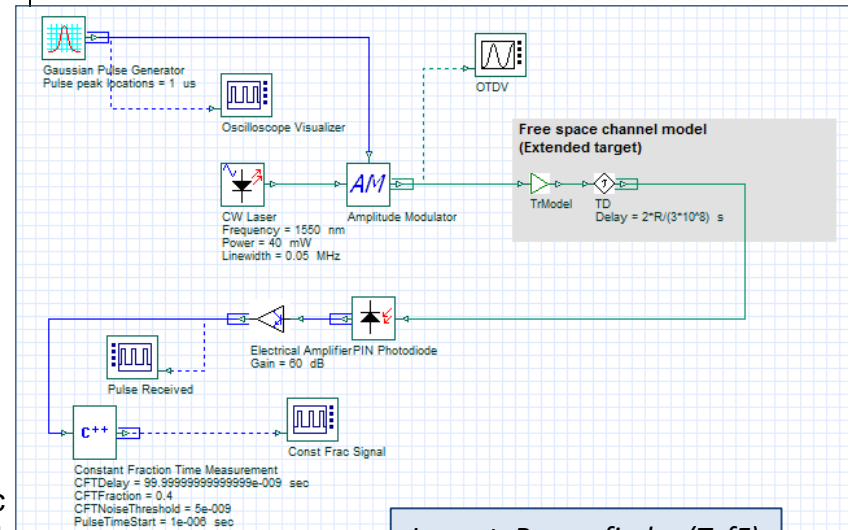
where P_t is transmitted optical power, D is the receiver aperture diameter, ρ is the reflectivity of the target, τ_{atm} is the atmospheric loss factor, τ_{opt} is the optical transmission system loss factor and R is the target range

- To reliably determine the time trigger for the arriving pulse, the Constant Fraction Time Measurement [3] method is used (implemented with our **Cpp Component**).

REF 1: Laser ranging: a critical review of usual techniques for distance measurement, *Optical Engineering*, Vol. 40, No. 1. (2001), pp. 10-19 by Markus C. Amann, Thierry Bosch, Marc Lescure, Risto Myllylä, Marc Rioux

REF 2: Ahmed H. Elghandour; Chen D. Ren; Modeling and comparative study of various detection techniques for FMCW LIDAR using OptiSystem, Proc. SPIE 8905, International Symposium on Photoelectronic Detection and Imaging 2013: Laser Sensing and Imaging and Applications, 890529 (September 19, 2013)

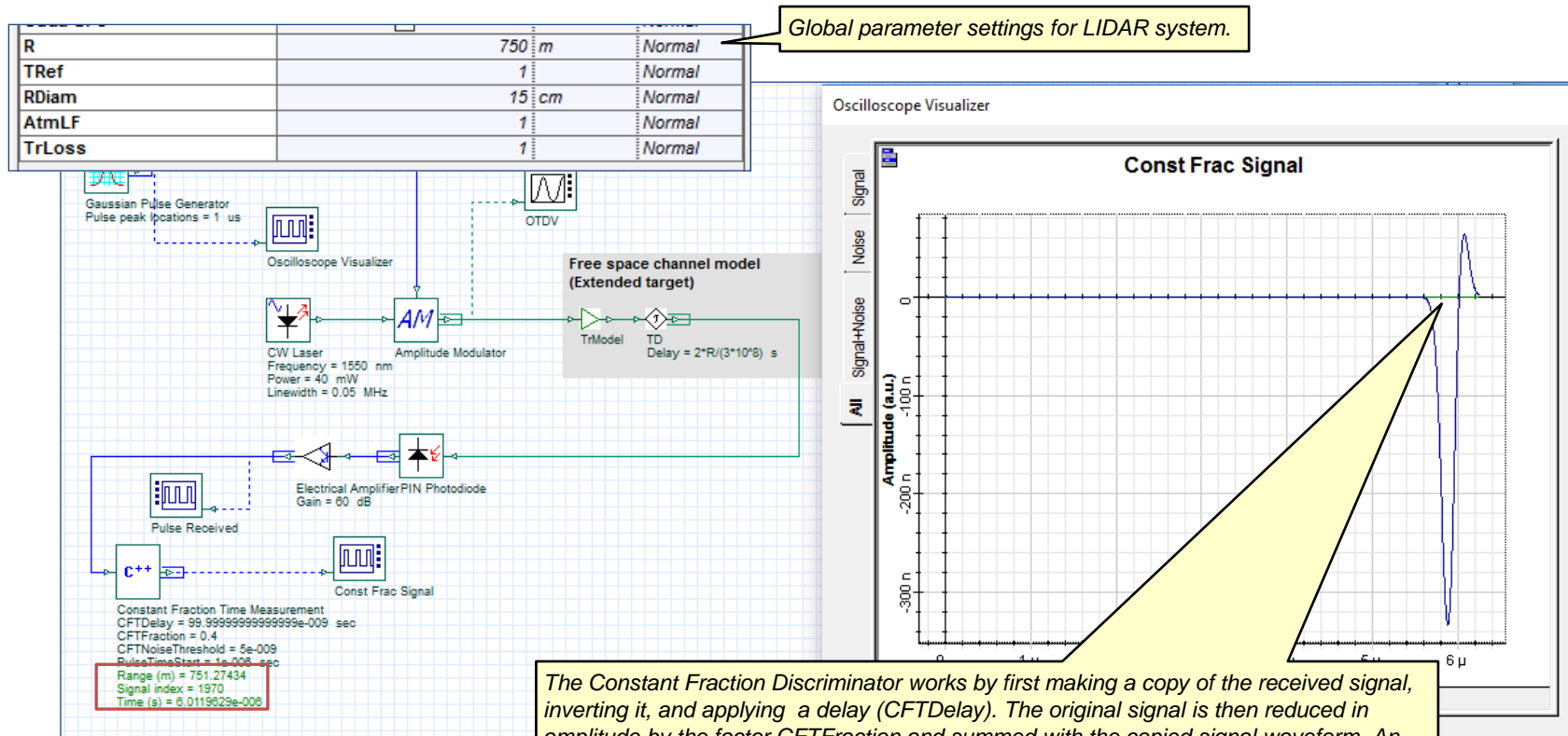
REF 3: Fast-Timing Discriminator Introduction, Ortec Inc., <http://www.ortec-online.com/-/media/ametekortec/other/fast-timing-discriminator-introduction.pdf?la=en> (accessed 10 Feb 2017)



Layout: Range finder (ToF)

Range measurement (Time of flight) (2)

- In the example below, a Gaussian pulse (Peak pulse time = 1 us) is transmitted optically and reflected from a virtual target (defined by the Free space channel model (Extended target)). After being subjected to attenuation and delay, the received signal is detected and post-processed by the Cpp Component **Constant Fraction Time Measurement**.
- The received pulse is time triggered at the time sample 6.02e-06 sec and in turn the range is found to be 751.27 m (compared to the global parameter range setting of 750 m). The sensitivity of the Constant Fraction Discriminator can be modified by changing the input parameters *CFTDelay*, *CFTFraction*, *CFTNoiseThreshold*.

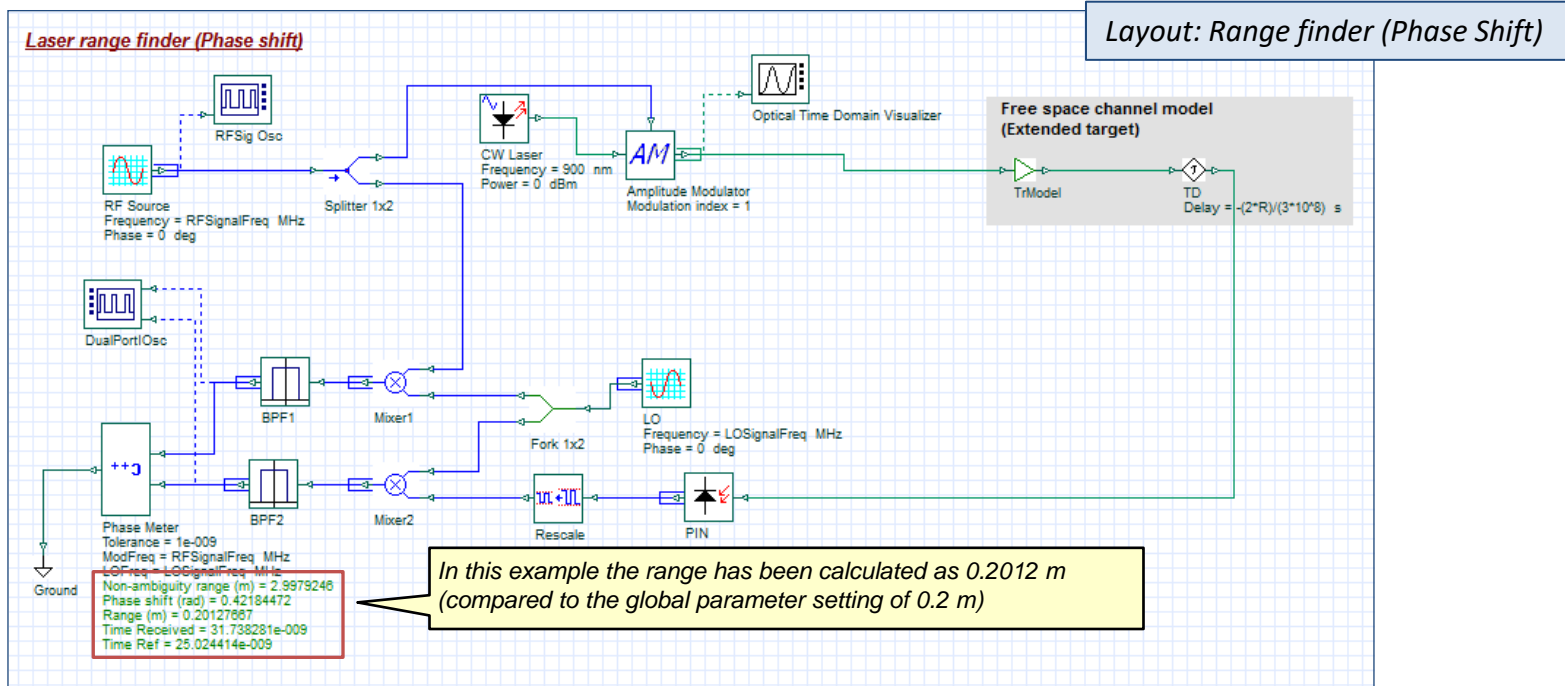


- Another way to measure the range of an object/target is with a phase-shift range finder. With this method, the optical source is modulated at specific frequency R_f and transmitted towards the target. The reflected signal is then detected with a PIN photodiode followed by a heterodyne receiver. The phase shift resulting from the transmission of the optical signal ($\Delta\phi$), relative to the original reference signal, is then measured and used to calculate the range as follows [1]:

$$R = \frac{c\Delta\phi R_f}{4\pi}$$

- To improve the accuracy of this system, the reference and received modulated signals can be mixed with a local oscillator R_{LO} to down-convert the received waveform to a lower frequency ($R_{LO} - R_f$). These signals are then band-pass filtered (to reduce noise) and processed by a Phase Meter (using our programmable **C++ Component**)

REF 1: Laser ranging: a critical review of usual techniques for distance measurement, *Optical Engineering*, Vol. 40, No. 1. (2001), pp. 10-19 by Markus C. Amann, Thierry Bosch, Marc Lescure, Risto Myllylä, Marc Rioux



- The last method to be presented is the frequency modulated continuous wave (FMCW) LIDAR. Two models have been developed: *FMCW LIDAR with Direct Detection* and *FMCW LIDAR with Coherent Detection*. Both models work on the same principle. A frequency modulated optical transmitter is sent out towards the target and the reflected signal is detected (by a photodetector) and mixed with the original linear frequency modulated (LFM) signal. As the received signal is time-delayed, an intermediate frequency signal is produced. Using a frequency counter (implemented with our **C++ Component**) the detected R_f signal is measured and then used to calculate the range as follows [1]:

$$R = \frac{R_f \cdot c \cdot \text{RampPeriod}}{2 \cdot \text{DeltaFreq}}$$

where the *RampPeriod* is equal to the global parameter **Time window** and the *DeltaFreq* is equal to the parameter **RFSweepBandwidth** (set within the component parameters of the Subsystem **RF LFM Waveform Generator**)

- The only difference between both detection systems is that one uses square law detection whereas the other uses a coherent homodyne detector to recover the incoming optical signal before mixing (the latter thus provides a higher sensitivity as the detection process is shot-noise limited)

REF: Ahmed H. Elghandour; Chen D. Ren; *Modeling and comparative study of various detection techniques for FMCW LIDAR using OptiSystem, Proc. SPIE 8905, International Symposium on Photoelectronic Detection and Imaging 2013: Laser Sensing and Imaging and Applications, 890529 (September 19, 2013)*

FMCW LIDAR System with Coherent Detection

Layout: FMCW Coherent Detection

