

Laser Range Finder for Air Borne Application

Neeraj Bhargava, Sushil Kumar, GS Rawat, SP Gaba
Instruments Research and Development Establishment, Dehradun-248008, India
Email: nbhargava@irde.res.in

ABSTRACT

Laser Range Finder (LRF) is a most commonly used sensor for non-contact distance measurement and its applications cover wide areas of civil and defense. This paper discusses the design of Time of Flight (TOF) based single channel pulsed LRF, in which single optical channel has been used for transmitting and receiving of laser pulse with the day sighting capability. It offers considerable size reduction over dual channel counterpart without compromising the performance of LRF. The LRF supports ARINC-429 interface to make the sensor compatible with avionics systems and multiple Pulse Repetition Frequency (PRF) to fulfill the varying data density requirements. The mechanical design of the LRF has been carried out to fulfill the airworthy requirements. Since the system requires alignment between transmitter, receiver module and day-sight graticule, precise beam steering mechanisms and movements have been provided. Environmental tests as per MIL Std 810E have been carried out on various mechanical sub-assemblies and electronic module to increase the reliability of the system. The performance of the LRF has been tested in practical scenario and found better than the dual channel LRF.

Keywords: Laser Range Finder (LRF), Time - of - flight (TOF), Pulse Repetition Frequency (PRF)

1. INTRODUCTION

Since its advent, laser has found tremendous applications in almost every area of science. Laser technology has found promising applications in the field of industry, medicine, scientific research and defense. The very high degree of coherence of laser has provided a new level of simplicity and accuracy in the development of variety of instruments. Lasers are commonly designated by the type of lasing material employed. The lasing medium can be a solid, gas, liquid or a semiconductor. Here, we are focusing our discussion on solid state laser based LRF.

Active optical sensors based on laser light are key devices for range measurement in space. LRF employing the time-of-flight technique cover applications spanning the entire ranging distance spectrum, from topographic mapping to rover navigation. They are a vital component of high precision targeting engagements. The precise and accurate range-to-target information is an essential variable in the fire control solution of today's sophisticated weapons. This range information is readily provided by the LRF.

A number of different techniques including Time of Flight (TOF), Phase shift and Frequency Modulation (FM) have been developed in recent past for distance measurement [1]. Phase shift technique calculates distance by measuring phase shift of transmitted and return signal and it gives good resolution but unambiguous range is limited. In FM technique, distance is proportional to frequency shift and this technique provides reasonable range and resolution but it has high electronics complexity. In TOF technique, time between the transmitted laser pulse and returned echo pulse is measured by electronic system and range is calculated by classical time, distance and speed relationship. This technique requires simple electronic design and it also works well for long ranges.

In this paper, single channel TOF based pulsed LRF design is discussed. The paper is organized in various sections. The LRF system overview is described in section 2 which is further subdivided into optical unit, as explained in subsection 2.1, laser trans-receiver unit, in 2.2 and mechanical design in 2.3. The results are provided in section 3 and finally the conclusion is drawn in section 4.

4. SYSTEM OVERVIEW

Single channel pulsed LRF works on the basic time-of-flight principle, where to and fro travel time is measured between LRF and target. The range R is calculated by following equation

$$R = c \frac{t}{2} \quad (1)$$

Where c is speed of light and t is to and fro travel time between LRF and target.

Electromagnetic principle of propagation says EM power get attenuated when it passes through atmosphere. The Laser shows similar behavior and it is given by the following empirical relation [2]

$$P_r = \frac{\rho P_t A_r A_T}{\pi R^2 A_B} T_t T_r e^{-2\sigma R} \quad (2)$$

Where P_r is received optical power at detector with aperture area A_r from non-cooperative target area A_t having reflectivity ρ at range R . Here P_t is transmitted power, σ is atmospheric attenuation and T_t, T_r are transmission of transmitting and receiving optics. A_T, A_B is target and beam area, the ratio of which is taken as 1 in case of extended target.

The single channel pulsed LRF system, as shown in Figure 1, can be broadly divided into two parts optical unit and trans-receiver unit. Optical unit is common optical assembly used by receiver, transmitter and day sight. In this unit, transmitter and receiver use same optical elements but day sight uses only objective and some other optical elements that gets separated with the help of beam splitter mirror. Laser trans-receiver unit mainly consists of control and interface unit, transmitter and receiver. It is responsible for both transmitting and receiving the laser pulse, range computation and interface. In this unit, both transmitter and receiver channel are separate. LRF requires wide variety of voltages levels to function properly, power supply unit provides all the required voltages to various parts of the system.

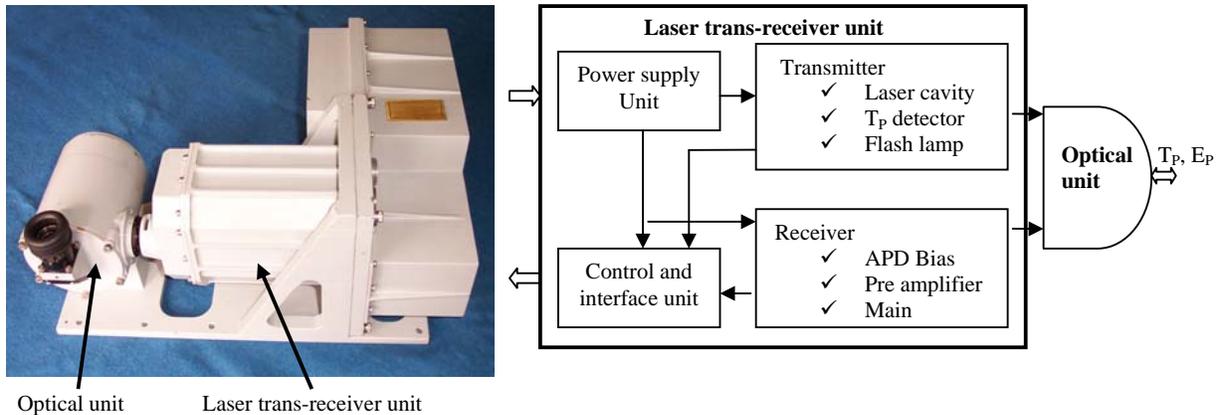


Fig. 1. Single channel pulsed LRF

2.1 Optical unit

This unit is a front-end optical assembly of the system and it is shared by transmitter, receiver and the day sight. The day sight consists of objective lens, roof prism for erecting the image, a graticule and an eyepiece assembly. Its magnification is 5X and FOV is 5°. The centre mark of the graticule, which is aligned to the laser transmitter and receiver, is used for locating the target during testing and alignment of LRF with other sensors during integration. The optical head unit acts as a collimator for laser transmitter. It expands the beam by 5 times thereby reducing the divergence of the laser beam to 0.8 mrad. The transmitted laser beam, after striking the target, is reflected back and is received by objective, with annular aperture of ϕ (85- 30) mm, of the optical head unit. It is then directed towards the receiving channel by bending prism in laser trans-receiver unit.

2.2 Laser trans-receiver unit

The laser trans-receiver unit consists of laser transmitter, laser receiver, power supply and other control electronics for operating the laser range finder. The high power laser beam generated by laser transmitter, with 4mrad raw beam divergence, is aligned with the receiver by wedge pair placed in front of the laser transmitter. It is then passed through a 6.4 mm hole in the bending prism and directed towards the front-end optical unit. Bending prism is rhomboid prism having a 6.4 mm hole on one of its face. This prism separates laser transmitter from the receiver. The received laser beam from the optical unit, when strikes the face of the prism with hole, reflects the beam from the outer surface towards the receiver channel whereas the portion of the beam passing through the hole does not contribute towards the detection.

2.2.1 Laser transmitter

The laser transmitter comprises of forced air cooled Cr⁴⁺:YAG Q-switched Nd:YAG laser cavity. A DC-DC converter charges the energy storage capacitor to the desired voltage. The energy stored in the capacitor is discharged through the pulse forming network to the Xenon flash lamp. The laser oscillations are obtained between the corner cube prism and the 50% reflective coating at one end of laser rod. The other end of the laser rod is AR coated. A 26VDC operated vane axial blower with 53 cfm airflow rate, guided by air duct, forces the air into the laser cavity through a slit of 50mm x 2mm to cool the laser rod, flash lamp and the Cr⁴⁺:YAG crystal. The laser cavity uses closed metallic reflectors so as to reduce the losses and maintain the temperature inside the cavity during high repetition rate operation. A PIN-photodiode is positioned axially, behind the corner cube prism in transmitter section, to generate a reference pulse for electronic processing unit.

2.2.2 Laser receiver

The laser receiver has a beam reducer, wedge pair assembly, an interference filter and an optical element to properly focus the returned signal at detector. The received beam after the bending prism is reduced to the size of interference filter by 2X beam reducer which is then steered towards the detector with the help of wedge pair assembly. The narrow band width interference filter, 100 Å° at 1064 nm, cuts the background noise and passes the signal to the focusing optical element for the detector. Si-APD detector, with an active area of 0.8 mm diameter, is used for detecting echo signal, of nW strength, received from the target. This detector requires a proper bias voltage which is provided by time variable and temperature compensated bias circuit. Time variable feature is given so that sensitivity for signals from remote location is more than for those from closer locations and temperature compensation is provided as the breakdown voltage of APD is temperature dependent. The detected signal is fed to preamplifier and main amplifier whose output gives the stop pulse for time measuring circuit.

2.2.3 Control and interface unit

LRF needs precise timing control signals to perform well to share the data during interfacing with bigger system. Control & interface unit is an important part of the instrument as it does all the control operations, range calculation and interface requirements. The hardware of this unit has been designed around 8-bit MCS51 family microcontroller [3] and for ARINC-429 interface, HI-8783 device is used.

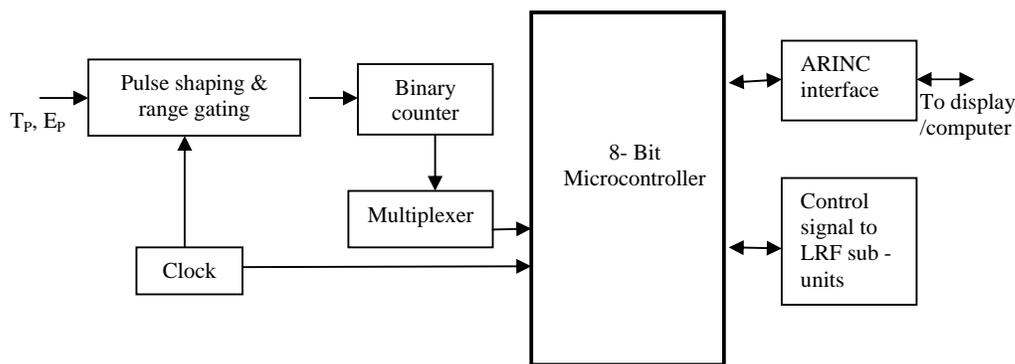


Fig. 2. Control and Interface Unit

This unit starts working on reception of commands through ARINC-429 channel. After checking the command validity, the controller generates control signals to LRF sub- units accordingly. As the laser fires, a transmitted pulse is received for timing reference and this pulse is used to start range gate after shaping it properly in pulse shaping circuit. The pulse shaping circuit stretches the distorted pulse of 20 ns to rectangular pulse of few microseconds. The stretched T_p and E_p is used for generating range gate which starts with T_p and stops with E_p . The clock passes only during the ON gate. The gated clock is used as an input to 12- bit binary counter which counts the number of pulses during range ON gate. The counter data is read by microcontroller using a multiplexer, and converts it into the range. Multiplexer is used in this design because of limited no. of I/O available in microcontroller.

The LRF works in three modes, i.e. main, standby and manual mode. By default, the LRF goes into standby mode, in which the rate of firing is 1 pulse per 4 seconds. In main mode, LRF fires at 2 pulses per second and manual mode is operated by switch, its rate is user dependent. Specific timings are required for each mode and all the timing routine are executed by microcontroller.

Generally the system available in market comes with standard serial communication, but in this system ARINC-429 interface is provided as it makes the instrument compatible for air borne applications. ARINC-429 employs transmission of 32-bits word and widely used in avionics equipments and systems. The first 8 bits of word are address bits and last 3-bits are used as a sign, status and parity bit respectively. The range data is converted into ARINC-429 format and sent to main computer or display unit.

2.3 Mechanical design

2.3.1 Trans-receiver structure

The components of the laser trans-receiver unit with the electronic cards are mounted on the trans-receiver structure. The structure was not only designed to withstand the loads, for which the FEA has been carried out but also to retain the alignment of the optical assemblies during the operation. The modular approach has been taken to design the transmitter & receiver units. These units have been tested before assembling on to the structure. Optical wedge pairs, with positive locking mechanism, have been provided for steering the laser beam during assembly and fine tuning of the system to cater for the misalignment of different modules due to the mechanical tolerances provided for fabrication. The resonance frequency of the structure has been kept quite high and the PCBs and other opto-mechanical assemblies have been placed on the structure so as to keep the centre of gravity of the assembly as near as possible to the mounting of the trans-receiver unit. The resonance frequency search has been carried out for the assembled unit to verify the design.

2.3.2 Environmental Hardening

Since the LRF is designed for airborne applications, it has to withstand the severe environmental conditions like low pressure & low temperature at high altitudes. According to pressure-altitude graph [4], the temperature at 11 kms altitude, drops to -40°C and the pressure to 200 mbar. The system thus requires sealing so as to isolate the inside air from outside environment. The design of the laser trans-receiver covers have been carried out to withstand the considerable drop in pressure, inside pressure being atmospheric, during the operations. The covers, with rubber gaskets, are screwed on to the main structure and proper adhesives are used to make the system leak tight. A desiccating unit, filled with silica gel crystals, and dry nitrogen, filled through purging non-return valve at a pressure slightly above atmospheric pressure, has been provided on the system. This purging valve is also used to check sealing of the laser trans-receiver unit and optical unit.

3. RESULTS

The performance of LRF is measured by its aligning accuracy and maximum range capability. For accuracy test we have used standard targets placed at different known distances. LRF is aimed at targets and the measured range is compared with known range. It was found that the LRF measured range with accuracy of ± 4 meters, which is as per desired specifications. The best method for testing maximum range capability is extinction ratio [5]; it is a ratio of output power to the minimum detectable power per unit area of the objective. In this method first extinction ratio is calculated for the maximum range and defined target as per design specification. In our design, for maximum range of 8 Km and target reflectivity of 0.1, the extinction ratio as given by equation below is 26.65 dB

$$S = 10 \log \left[\frac{\pi R_{\max}^2}{\rho} e^{2\sigma R_{\max}} \right] \quad (3)$$

Extinction ratio for standard target at 500m having target reflectivity 0.95 and neutral density filter attenuation N dB is given as.

$$S = 10 \log \left[\frac{N \pi R^2}{\rho} e^{2\sigma R} \right]$$

$$S = N - 0.22 \quad (4)$$

From equation (4) and (5), $N = 26.87$ dB.

Theoretically with neutral density filter of $N = 26.87$ dB, 50% of range should be obtained at 500 m away target then only the LRF can achieve 8 Km maximum range. We found in our test that with 26.87 dB attenuation, 70% of the range is obtained which fulfills our maximum range requirement.

The LRF has undergone various environmental tests as per graphs shown below:



Fig.3. Combined test

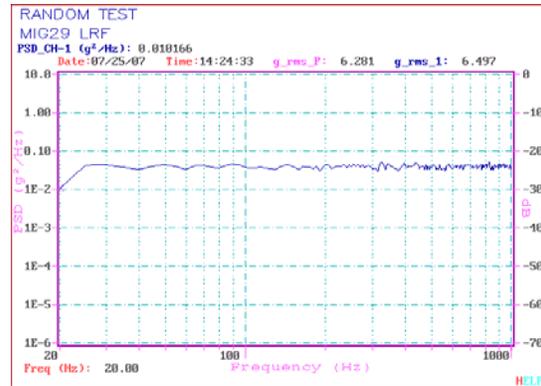


Fig.4. Random test at X axis

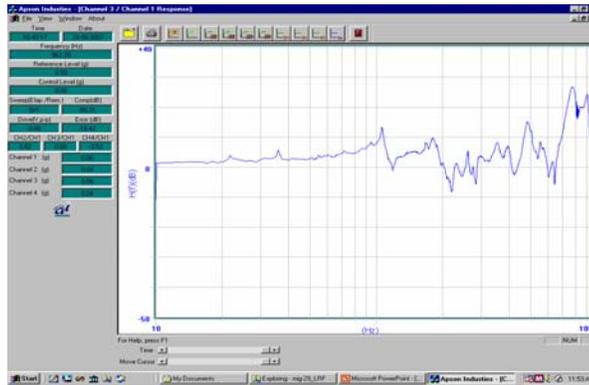


Fig. 5. Resonance search test at X axis Accelerometer position at front top

4. CONCLUSION

The performance of single channel LRF has been tested in various weather conditions and found good. The maximum range of 8 Km was measured with accuracy of ± 4 meters. The instrument has passed all the extreme environmental conditions and it can be used for avionics applications. Single channel used for transmitting and receiving laser beam, offers size reduction of LRF over dual channel counterpart without compromising the performance of LRF. The added feature of ARINC-429 widens the application platform of this instrument.

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