Microcontroller Based Electronic Clock for the Measurement of Time of Flight (ToF) Of High Speed Objects

Rajeev Dhanda
Department of ECE
N. C. College of Engineering
rajeevdhanda208@gmail.com

Navraj Khatri
Department of ECE
N. C. College of Engineering
navrajkhatri89@gmail.com

Deepti Jaglan
Department of ECE
N. C. College of Engineering
deeptijaglan@gmail.com

Abstract

The system based on the principles of "speed = distance/time". The designed system includes an electro-optical unit, an optical sensor, a data-acquisition & processing unit and LCD display or CRO unit. When a projectile crosses through a laser screens formed by the electro-optical unit, the scattered effect by the flyer produces an increase in the energy falling of the photo-detector, which in turn creates a momentary increase in the output current of the photo-detector. For high-speed components, the output noise of the photo-detector increases exponentially with the speed of the projectile whereas the signal amplitude decrease, which reduces the signal-to-noise ratio (SNR). The optical sensor is used for amplifying and signal conditioning.

Keyword- *electro-optical unit, optical sensor, data-acquisition & processing unit, CRO, scattered effect, momentary, signal-to-noise, signal conditioning.*

1. Introduction

The technique of measurement of time of flight of a projectile between two fixed planes is continuously employed to determine the speed of high speed object. When the projectile successively crosses through the first and the second laser screen, the start and stop pulse signal can be obtained as the triggering signal for the timer. To measure the time interval between the start and stop pulse signals, the time of flight (TOF) can be obtained and by processing and calculating, the average velocity of the flyer will be acquired. Comparing with the conventional laser screen method, the benefit of the new design is obvious. Since the laser screens do not direct onto the photo-detectors, avoid the saturation state of the photo-detector at the time when the projectile does not pass through the laser screen. Then, the high-power laser and high-sensitive photo-detector can be used to measure the velocity of small-calibre flyer (1mm or smaller in diameter). Therefore, this Improvement will be suitable for high-speed small-calibre flyer velocity measurement.

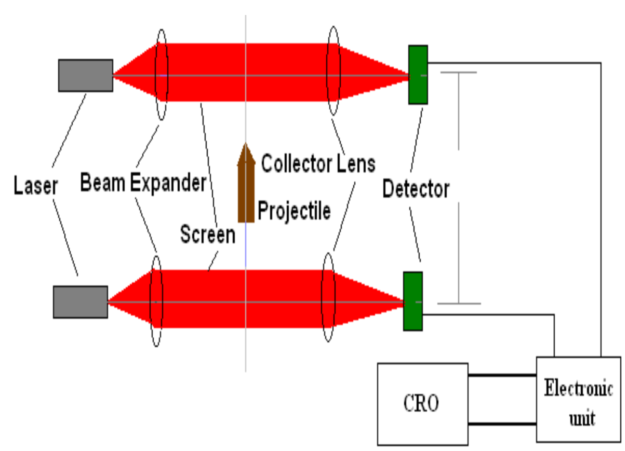

Figure 1. System Block Diagram

Development of the system is based on optical principles, but applications are in field of ballistics. Ballistic is the science of mechanics that deals with the flight, behaviour and effect of projectiles. Terminal ballistic study is the study of motion and consequent effect of projectiles as they interact with their intended target [1]. Target may resist projectile at low velocity, but it may not be resistant to projectile fired at higher velocity. The target may be bulletproof vest, glass (such as in vehicle window), the body of vehicle, helmet, or a human body. After the impact of projectile on the target, the movement of debris (fragments) coming out of the target can be used to measure the stopping power of the target with regard to projectile. These data can be used to estimate the damage to a target, and damage data can be used to design the armour for better shielding. The target is said to be fully bulletproof if, upon contact with projectile, no debris comes out. The basic application of this system is to test the impact of projectile on the target. The impact data can be used to test the performance with regard to a projectile having a particular velocity keeping in view the specified requirement of target [2].

2. Design and Description of the System

To determine the speed of high speed object by measuring the time of flight (ToF) between two parallel laser screens concept is used.

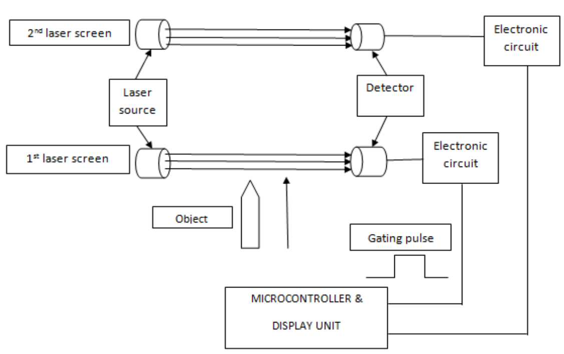

Figure 2. Schematic of the system

Whenever a projectile crosses either of the screens the corresponding photo-detector senses the event, due to partial or full obscuration of the incident energy. The change in light flux is transformed by photo detector into electronic signal. The weak signal is amplified, filtered by signal conditioning, and then sampled by data acquiring devices. This electrical signal is used to trigger the microcontroller to start/stop the timer to measure the time of flight of projectile between two laser screens. The system consists of two units: Optical unit and Data - acquisition and Electronics unit. The optical unit incorporates two similar laser screens. Each laser screen consists of a laser- beam expander-collimator called source assembly, a slit of 1mm collimating lens make laser screen and a lens-photo detector (converging lens) called detector assembly.

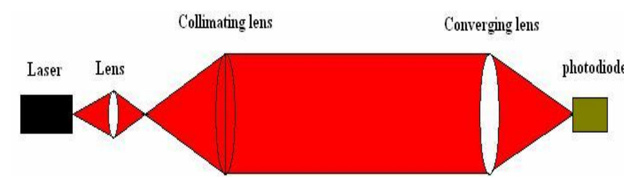

Figure 3. laser screen

A. Laser-Laser produces a beam of coherent light with a specific wavelength in the infrared, visible or ultraviolet regions of the electromagnetic spectrum. Semiconductor lasers have been used in the project. A semiconductor laser diode is a pn-junction of GaAs or GaAs combined with other materials is manufactured with a precisely defined length L [3].

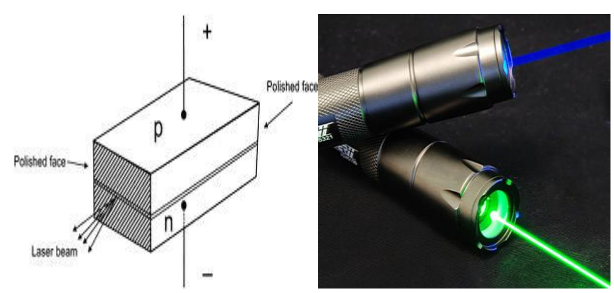

Figure 4. Semiconductor laser diode

B. Converging lens- If the lens is biconvex or Plano-convex, a collimated or parallel beam of light travelling parallel to the lens axis and passing through the lens will be converged (or focused) to a spot on the axis, at a certain distance behind the lens (known as the focal length). In this case, the lens is called a positive or converging lens.

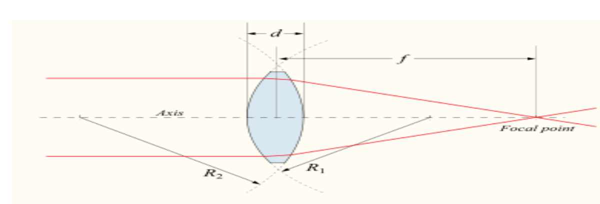

Figure 5. Converging lens

C. Diverging lens- If the lens is biconcave or Plano-concave, a collimated beam of light passing through the lens is diverged (spread); the lens is thus called a negative or diverging lens. The beam after passing through the lens appears to be emanating from a particular point on the axis in front of the lens; the distance from this point to the lens is also known as the focal length, although it is negative with respect to the focal length of a converging lens.

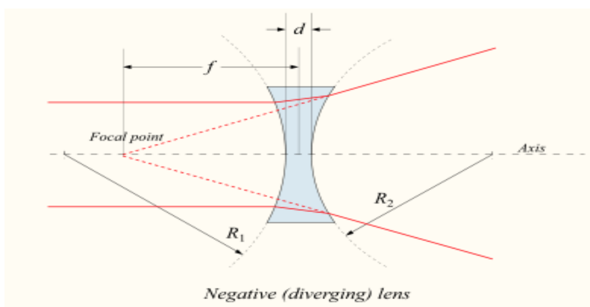

Figure 6. Diverging lens

D. Laser Screen using Prism-By using refraction technique a double screen can be made. The prism assembly is comprised of a set of 45º-90º-45º prisms and two plates made of plate glass [4-5]. The prisms, made of optical glass, are mounted between the plates in such a way that their hypotenuse faces are coplanar and parallel to each other. The length and width of the hypotenuse face of a prism defines the cross section of the expanded collimated laser beam, used for construction of the laser screen.

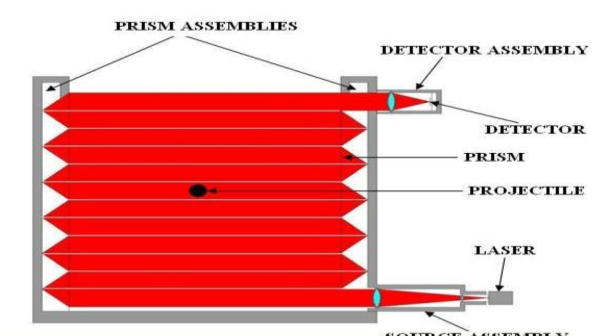

Figure 7. Making of laser screen by using prism

The prisms are aligned in a specific way such that when laser light is thrown on one side of the prism, it is refracted and will come out from the other face parallel to its previous ray of light of laser.

E. Data Acquisition and Electronics Unit- When the projectile interrupts the first laser screen there is a decrease of laser light energy which is falling on the photo detector. So the output current of the photo detector decreases simultaneously. The output of the photo detector is fed to a current to voltage converter and then further to a pre-amplifier, as the output signal of the photo detector is very weak [6]. After that the signal is send to a subtractor to subtract the noise from the signal and then finally it is given to the input of a monoshot circuit which generates a TTL pulse or triggering signal.

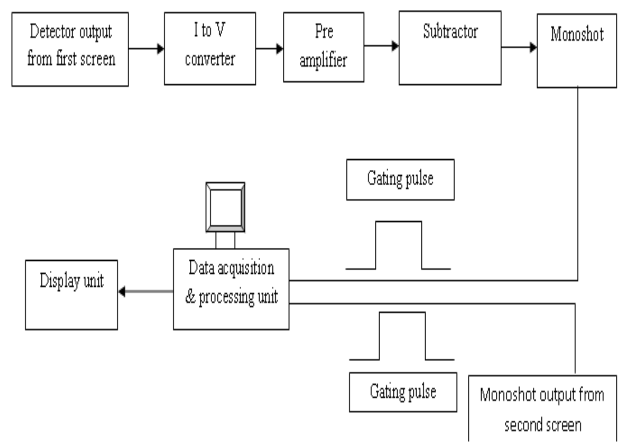

Figure 8. Block diagram of electronic unit

To make the screen sensitive to projectiles as small as 5mm very high speed operational amplifiers have been used to amplify the signals. For high speed components the output noise of the photo detector increases exponentially which reduces the signal-to-noise ratio (S/N) [7].The pre-amplifier and the signal conditioning circuit are designed to minimize the noise.

F. Photodiode-Silicon photodiodes are semiconductor devices responsive to high-energy particles and photons. Photodiodes operate by absorption of photons or charged particles and generate a flow of current in an external circuit, proportional to the incident power. Photodiodes can be used to detect the presence or absence of minute quantities of light and can be calibrated for extremely accurate measurements from intensities below 1 pW/cm^2 to intensities above 100 mW/cm]^2[8].

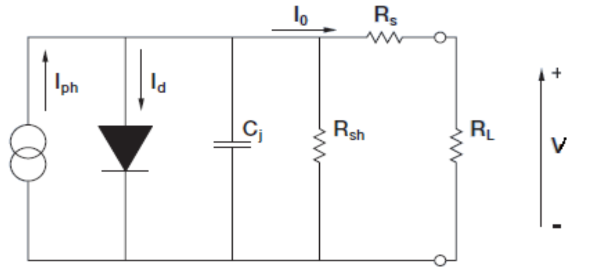

Figure 9. Equivalent Circuit for the silicon photodiode

G. Current to Voltage Converter and Pre-amplifier- The photo-detector has been used in photoconductive mode with reverse bias to improve the response and responsiveness. Since there is no internal gain in PIN5DI photo-detector, the performance of the whole system mainly depends on the pre-amplifier which is used for converting the photocurrent of PIN5DI to voltage signal. It further present an improved composite trans-impedance pre-amplifier with wide-bandwidth (BW) composed by microwave transistors and operational amplifier (OP-AMP). The output of the op-amp A_2 recorded to CRO [9].

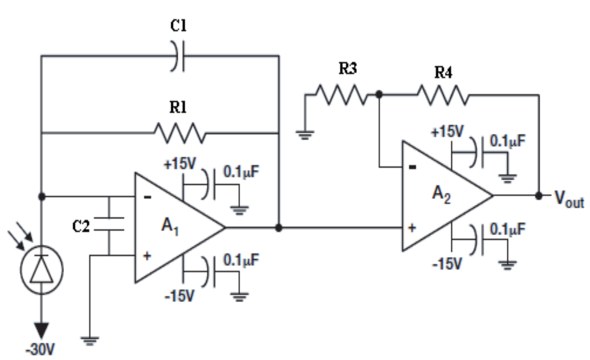

Figure 10. Current to Voltage Converter and Pre-amplifier

H. Microcontroller- The heart of the circuit is the P89V51RD2 microcontroller. The controller is used to sense the interrupt when projectile cross the 1st optical screen and it starts the timer and similarly when projectile cross the 2nd optical screen it stops the timer. P89V51RD2 microcontroller is operated at frequency of 40MHz using crystal oscillator. P89V51RD2 microcontroller is used in the project. This microcontroller takes 12 clocks to execute single instruction cycle. So as microcontroller is operated at frequency of 40 MHz, so to execute single instruction cycle it will take time period of 300 ns.

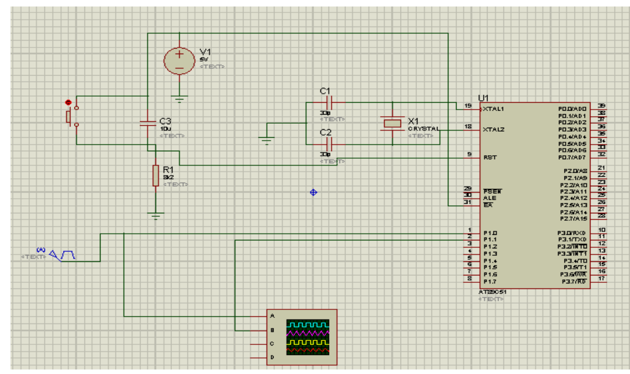

Figure 11. Microcontroller Based Electronic Circuitry for measurement of pulse duration

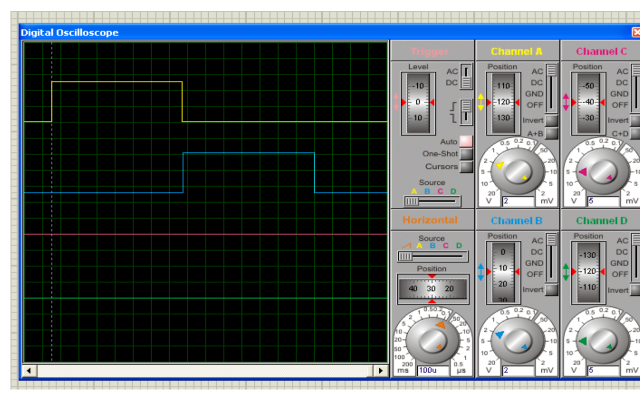

Figure 12. Testing of Microcontroller Circuit having pulse duration of 700µs using proteus software

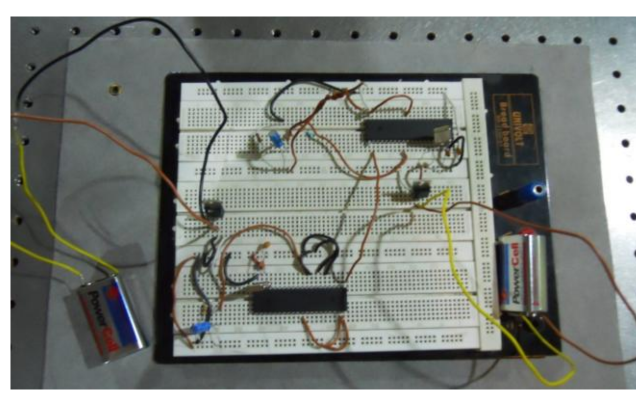

Figure 13. Circuit made on breadboard to generate pulse

As shown in figure 13 there are two microcontroller P89V51RD2 one for generating the pulse in range of micro second to nano second and another is used to verify the pulse wheather it lies in the range or not. Microcontroller are programmable due to which we can chanege the pulse duration and in spite of this we can vary the delay also.

I. Software- During this project lot of software are used. First of all we burn program code into a microcontroller. Some steps are executed to accomplished this task. Program is written in kiel software editor by creating a Project in kiel as shown in figure

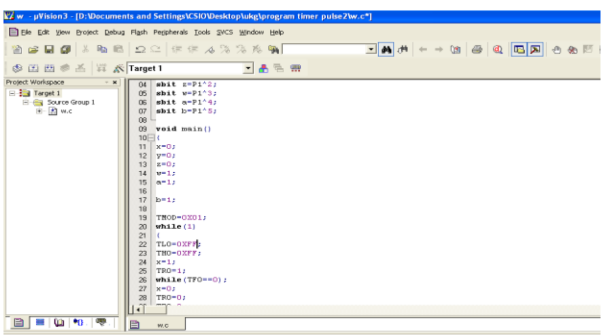

Figure 14 . Kiel Software

Then Project is bulid and errors are checked by compiler. If there is no error then project is built and hex file will be created by software.

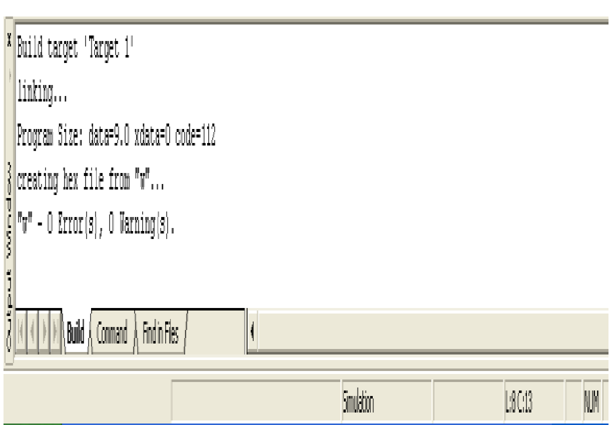

Figure 15. Kiel compiler

Then using Debug session pins of microcontroller is montored by viewing peripheral and timers . Using Proteus Simulator, simulation is done in order to check virtual working of I/P pins and O/P pins.

As the simulation result is according to our expectation, the program code is burn into microcontroller using

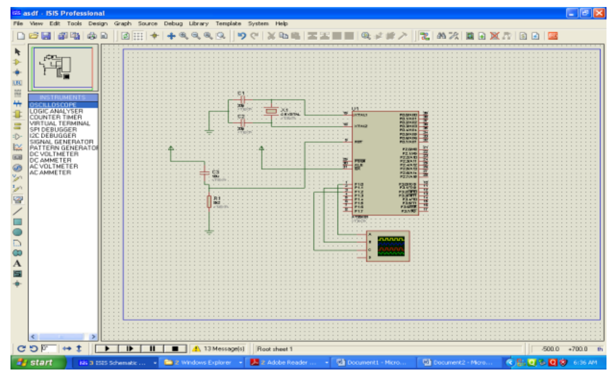

Figure 16. Proteus simulator

SuperPro Programmer kit. Using superpro software, Hex code created using Keil software is burned into microcontroller. Then hardware circuit is made, our microcontroller is fitted in the circuit and output results is obtained on CRO. Pulse of different duration was given input to microcontroller. Microcontroller counts the duration and show the output on CRO the duration of pulse measured.

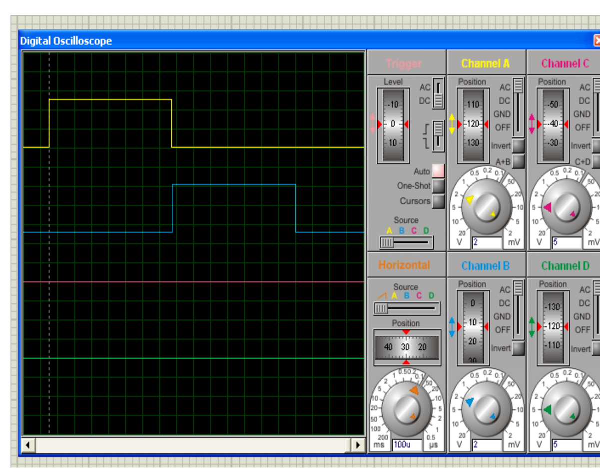

Figure 17. Simulation results using proteus software

We found that simulation results and actual results matched and microcontroller selected work according to our requirements.

3. Working Principle- Whenever an object crosses either of the screens, the detector senses the event due to partial or full obscuration of the incident energy.

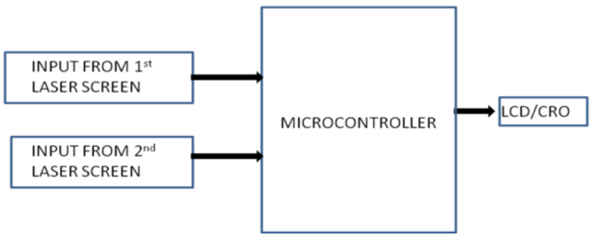

Figure 18. System Implementation Diagram

As a result a triggering pulse is generated that is used to start/stop the clock.A microcontroller based electronic circuitry is implemented to accurately record the ToF. Velocity of high speed object is determined by measuring the time of flight (ToF) of the object crossing the laser screens and distance between the screens [10].

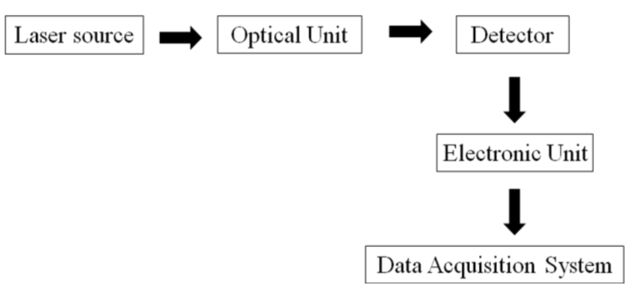

Figure 19. Block diagram of Time of Flight measurement system

Velocity = Distance / ToF

Interruption of Laser Screen by Projectile

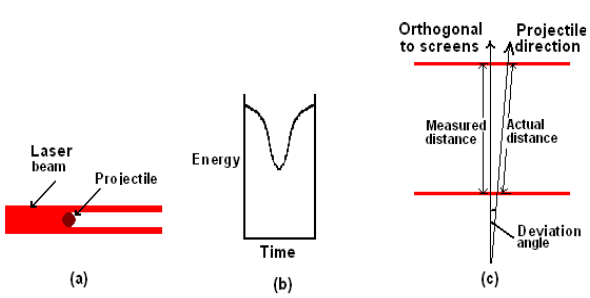

Figure20. Projectile Trajectory: (a) Beam Interruption, (b) Energy Curve
And (c) Distance Measurement Error due to Deviation Angle

The interruption of the first laser screen by a projectile produces a decrease in the energy falling on the photo detector, which in turn creates momentary decrease in the output current of the photo detector. To make the screen sensitive to projectile as small as 5mm, very high speed operational amplifier has been used to amplify the signals [11-12]. The system has a provision for measurement of the speed of a projectile in three ranges slow medium and fast. For a projectile whose speed changes rapidly, the screens have to place nearer to each other; the system has a provision to do so.

4. Sources of Error - If the projectile is not orthogonal to laser screen it can give distance errors. Performance of the photonics based speed measurement system depends upon the how accurately the TOF and the distance between the screens, through which smallest projectile moving with the fastest speed passes, are measured [13].

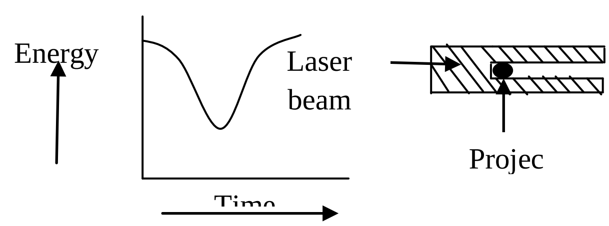

Figure 21. Distance measurement error due to deviation angle

Speed of the projectile under test is measured as ratio of the distance between the screens and the TOF and the uncertainty in the measurement of the speed depends on these two parameters. The speed measurement based TOF is governed by following equation; $S = X/t_0$ .... (1)

Taking log both side in equation (1)

$$\log_e S = \log_e X - \log_e t_0$$

Differentiating the above expression with respect to S

$$1/S = 1/X\,(dX/dS) - 1/t_0(dt_0/dS)$$

$$dS/ S = dX/X - dt_0/t_0$$

Representing the limiting errors in X and t_0 as +/-dX and +/-dt_0 respectively and considering the worst condition when

$$dX/ X = +ve \text{ and } dt_0/ t_0 = +ve$$

The relative error in the speed depends upon relative error of distance and time and

Represented by the following equation;

$$\mathbf{dS/ S = dX/X + dt_0 / t_0} \qquad \ldots\ldots\ldots(2)$$

Where **S**: Actual value of the speed, **X**: Distance between the laser screens , $\mathbf{t_0}$ **:** Time of Flight (TOF)

And $\mathbf{dt_0}$, **dX** are the errors in the measurement of TOF and distance between two screens, respectively and which in turn produces **dS** error in the measurement of speed according to the equation (2).

There are two types of errors viz. instrumental error, which depends upon accuracy of the components and assemblies as well as alignment errors and experimental error, which depends upon the deviation of the projectile trajectory from the direction perpendicular to the screens [14].

5. Result- The experiments were performed in PHOTONICS Lab of CSIO. The evaluation of the measurement accuracy in this kind of metrology system is very important since it is related to the tested velocity. A number of experiments were carried out to verify all the specification of the system.

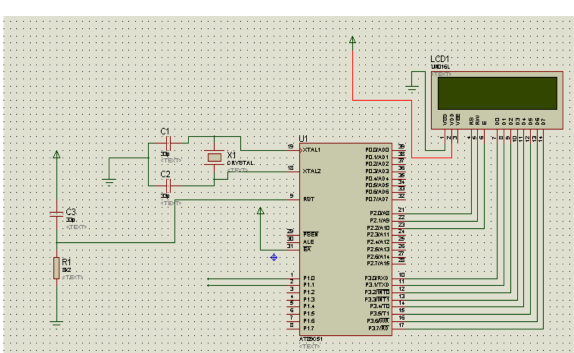

Figure 22. Circuit diagram for measuring time of flight

Table 1 Test Result was carried out at CSIO photonics lab and speed data in parentheses were supplied by the manufacturers. Distance between two laser screens is 300 mm.

Projectile type	Speed (m/s)
Paper ball thrown by human arm with different muscular effort.	13.00 14.44 14.06 15.98
Steel ball thrown by human arm with different muscular effort.	5.19 7.47 8.17 7.98
Air pistol (0.22-in, lead pellet)	71.94 64.51 72.46 68.02
Semi machine carbine (SMC) pistol (9 mm) (397+15 m/s)	401.28 397.26 409.64 402.74
SLR rifle (7.62 mm) (817+9 m/s)	820.67 814.56 808.21 811.91

6. CONCLUSION- The main advantage of the described system are as follows:The system is innovative, compact, and inexpensive. Microcontroller based electronic circuitry has been designed and developed to record TOF accurately. Internal timer of microcontroller has been employed to measure ToF.

TOF measured by microcontroller is used to calculate the velocity of the object and to execute it LCD is interfaced with microcontroller to display velocity.

Acknowledgment

With a deep sense of gratitude and heartiest honour, I would like to express my immense thanks to Dr. Pawan Kapur, Director, Central Scientific Instruments Organization, Chandigarh for providing me all the facilities to pursue my dessirtation to its successful accomplishment.I proudly acknowledge my sincere and heartfelt thanks to Mr. R.C Kalonia, Senior Principal Scientist, V-4(Photonics Division), CSIO for their valuable and sustained guidance, constant encouragement and careful supervision during the entire course which made the project successful.

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