A low cost CPLD based shotgun shell calibration system

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Abstract

This paper describes a shotgun shell calibration system developed in VHDL [1], [2] and implemented both on a FPGA and a CPLD. The proposed system implements three chronographs to measure travel time from the muzzle of the gun to a target placed ten meters away. Measured time is sent to a microcontroller through a shift register circuit also developed and implemented for this system. The time of flight measurements are made with an accuracy of 1 us. This accuracy allows a less than 0.1% computation error of shell velocity. The system was successfully tested for shotgun shells with 500 m/s muzzle gun speed. The final implementation was done on a coolrunner CPLD from Xilinx. The CPLD implementation allowed the calibration system to be built at a low cost, which enables its use even by small shot gun shell manufacturers.

Keywords: CPLD, FPGA, VHDL, Time Measuring, Shotgun shell.

1. Introduction

Shot gun shells are commonly used both in hunting and sports activity. Several different types of gunpowder and slog charges are needed for both activities depending on the type of game animals, targets, weather conditions, distance, among others.
Shotgun shell manufacturers sell their ammunition based on a set of characteristics ([3], [4]) that must be tested and calibrated on a sample and test methodology. These characteristics include the shell's initial velocity as well as its decrease after 1 and 10 meters flight. Special environmental conditions regarding temperature, humidity and barometric pressure should be met during the tests. For these reasons calibration systems are expensive and are not usually achievable by small shot gun shell manufacturers.
This paper presents a low cost CPLD implemented shotgun shell calibration system developed with the collaboration of the Portuguese company ISA – Intelligent Sensing Anywhere, S.A. and implemented for one of its clients. The system is based on a VHDL description [1], [2] circuit.
Chapter 2 describes the overall system and the time measurement methodology. Chapter 3 details the counting circuit and Chapter 4 describes the implemented communication solution also developed. Results are shown in Chapter 5.

2. System description

The system's project is based on a set of three chronographs triggered by four sensors [4]. The main trigger is also the gun's trigger so that when a shot is fired also the time counting is started. At the muzzle of the gun a photoelectric cell was placed as well as a second photoelectric cell placed one meter apart. The target impact sensor was placed ten meters down range. The first chronograph measures time between the gun's trigger and the muzzle's gun photocell. The second chronograph measures the travel time at one meter down rage. The third and final chronograph measures the time the shot gun shell takes to reach target. A chronograph system diagram is shown in Figure 1.

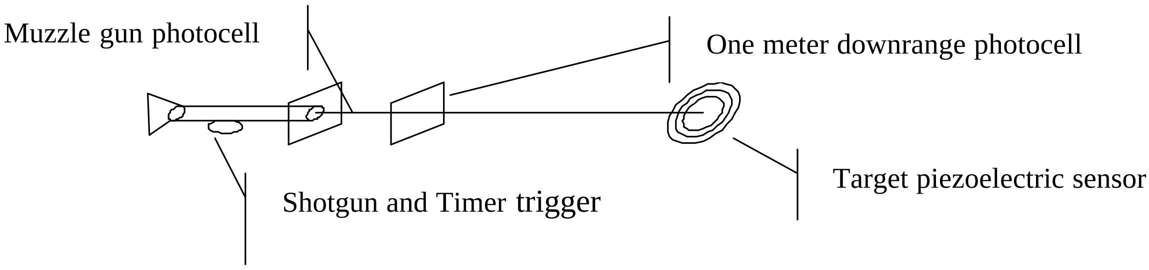

Figure 1 – Chronograph system diagram.

The main trigger, the two photocells and the piezoelectric impact sensor are connected to a analog front end built with a simple LM339 comparator/amplifier that provides high input impedance and hysteresis feedback to reduce noise level caused by input bouncing. This input bouncing, observed at the output of the photocells, and the piezoelectric sensor, is caused by the high dispersion of the lead charges as they travel through the air. Care was taken at the analog front end so that the following digital circuit only needs to deal with part of the effects cause by the sensor's bouncing. Also noise level reduction is needed because of the very small time pulse sent by the photoelectric sensors when crossed by the shot gun shell.

Special care was taken with photocell polarization and power feed because of the need to have a very fast response – high slew rate – on both photocells.

Together with a time measuring circuit a communication circuit was also developed. The time counting is sent to a PIC microcontroller by a shift register whose clock is also controlled by this system. The shift register circuit was developed so that it can be connected to any interrupt driven pin of a common microcontroller.

The timing circuit was implemented on a Xilinx Spartan 3 FPGA [6], [9], [12]. The circuit was later ported to a Xilinx Spartn 2 FPGA [7], [8] and was finally implemented on a Xilinx CollRunner 2 CPLD [10], [11]. All three implementations use a 50 MHz input clock.

3. Timing circuit description

Figure 2 shows the developed circuit block's diagram. Three cascade frequency dividers where developed to provide the circuit with general purpose utility. A 24 bit BCD counter is driven by one of the frequency dividers. BCD numbering format was chosen so that no binary to BCD decoding is needed.

M1, M2 and M3 are three sensor driven latch registers that store BCD counter value at the time a shotgun shell crosses each photocell. M1 stores the time at the muzzle of the gun. M2 stores the travel time at one meter down range and M3 stores the time at target hit. The gun's trigger starts BCD counting.

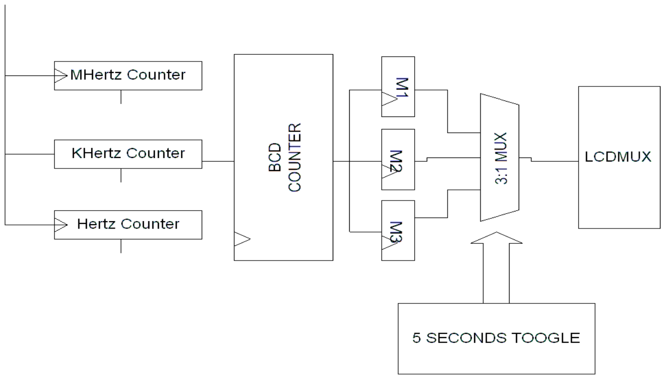

Figure 2 - Systems block diagram.

The latch inputs M1, M2 and M3 are debounced providing additional noise level reduction to the timing measurements.
The circuit was developed using the Xilinx Free webpack and results in the resources occupation for the Xilinx Coolrunner 2 CPLD implementation shown in Table I.

Table I – Resources occupation for the Coolrunner 2 CPLD implementation

	Macrocells	Product Terms	Functions Blocks	Registers	Pins
Used	219	471	322	216	12
Total	256	896	640	256	118

4. Calculation and display of the calibration parameters

Timing data can be viewed both locally and in a remote computer. BCD data is visualized on a 7 segment LCD display if the system is implemented on a Digilent Inc Spartan 3 Starter board. On all platforms (Spartan3, Spartan2 and CoolRunner) a 72 bit shift register sends data to any off-the-shelf microcontroller. The implemented circuit has control over the shift register clock. Data is shifted at a 1 kHz clock rate.
The shotgun shell velocities can be calculated using an off-the-shelf software package[4]. This software solves the diferential equations [5] for bullet flight using a Runge-Kutta 4^{th} order method. Future development for this system includes hardware based solving of bullet flight differential equations.
The special environmental conditions regarding temperature, humidity and barometric pressure are met by measuring these values using appropriate sensors.

5. Results

The developed system is working correctly as it measures time in accordance with client specifications. Table II shows a set of timing data measured by the system for different types of shot gun charges. The timings presented in Table II are also compatible with catalog data specifications of observed shot gun shell manufactures.

Table II – Set of results measured by the developed system

Muzzle of the gun time (ms)	One meter time (ms)	Target time (ms)	Velocity calculation error (%)
001706	004537	031784	0,07%
001023	003634	029936	0,08%
000602	003092	028852	0,08%
000883	003533	029555	0,08%

A software tool was also developed to view results from present and past shotgun tests. Figure 3 shows a screenshot of the developed software tool.

(a) (b)

Figure 3 – Screenshot from developed software tool.

6 . References

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