Developing Laser Spot Position Determination and PRF Code Detection with Quadrant Detector

Mohamed Fathy Heweage, Xiao Wen, Ayman Mokhtar, Ahmed Eldamarawy

Abstract**—**In this paper, we are interested in modeling, simulation, and measurement of the laser spot position with a quadrant detector. We enhance detection and tracking of semi-laser weapon decoding system based on microcontroller. The system receives the reflected pulse through quadrant detector and processes the laser pulses through a processing circuit, a microcontroller decoding laser pulse reflected by the target. The seeker accuracy will be enhanced by the decoding system, the laser detection time based on the receiving pulses number is reduced, a gate is used to limit the laser pulse width. The model is implemented based on Pulse Repetition Frequency (PRF) technique with two microcontroller units (MCU). MCU1 generates laser pulses with different codes. MCU2 decodes the laser code and locks the system at the specific code. The codes EW selected based on the two selector switches. The system is implemented and tested in Proteus ISIS software. The implementation of the full position determination circuit with the detector is produced. General system for the spot position determination was performed with the laser PRF for incident radiation and the mechanical system for adjusting system at different angles. The system test results show that the system can detect the laser code with only three received pulses based on the narrow gate signal, and good agreement between simulation and measured system performance is obtained.

Keywords**—**4-quadrant detector, pulse code detection, laser guided weapons, pulse repetition frequency, ATmega 32 microcontrollers.

I. Introduction

4-QUADRANT detector is an effective optical sensor which is commonly used in fiber optics measurements, alignment, laser receiver decoder, and free space optical communication. Laser guided and tracking weapons (LGWs) are playing very important role with the laser target tracking.

In this paper, we will present the 4-quadrant detector model and implement it with the spot position determination circuit including laser pulse coding based on PRF.

The model includes the preamplifier, post amplifier, inverse amplifier and the analogue to digital converter (ADC) in addition to PRF model and QD modelling and implementation [2], [3]. The laser spot position determination system is implemented based on QD and PRF technique. ATmega32 microcontroller was used to get the output from the ADC, PRF and perform the processing on the signal to evaluate the position information by the software, and show the position on the computer by serial port [1]-[3]. Laser pulse code and decoding is an anti-jamming system used in SAL guidance weapon technology. The semi-active laser tracking system with PRF gives the system ability to detect and recognize the codes and locked the target [4], [15].

The laser tracking system of spot detection with PRF [5], [6], [16]. LGWs use laser of a specific pulse code, which produces laser echo from the target, including a gate window. LGW uses its processing circuit to detect the reflected pulse. Based on the detection of a certain pulse code, the electronics circuit of tracking is commanded to hit the target reflecting the laser beam energy with the locked pulse code. In this work, an MCU is used to primarily detect the locked pulse code and separate it from the jamming code. The false code may come from buildings, jammer, the trees reflections, etc. or the sent cheating jamming pulse code to mislead the missile [7]-[9].

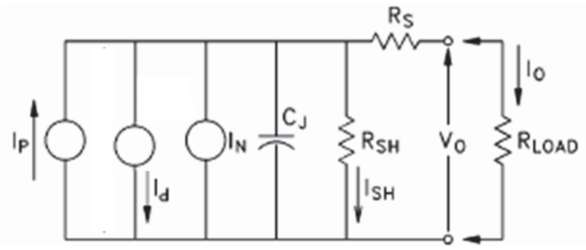

Fig. 1 Equivalent circuit diagram for the photodiode

Fig. 1 shows the diagram of the equivalent circuit for the photodiode where IP is the photogenerated current, IN is the internal noise current, Id is the dark current, RS is the series resistance, RSH is the shunt resistance, CJ is the junction capacitance and the output photocurrent is taken at the load of the detector [3], [4].

The user interface can be generated by PC serial interface and Proteus software comport interface. This paper can be organized as follows: In Section II, the photodiode model is discussed which includes the photodiode model based on pspice tool; in Section III, there are Proteus application and hardware implementation; in Section IV, there are simulations and results; and finally, conclusion is given in Section VI.

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II. Photodiode Modeling

The proposed photodiode model based on ORCAD pspice tool system is discussed.

The photodiode modelling equation principle is studied [3]. The ORCAD tool is used to model and simulate the photodiode output [2]. Then the output is compared with the datasheet or measured data. The photodiode circuit model is represented by each equation, then the model is built, where each block of the model represents a set of equations which provide the simulation of the photodiode behavior. Fig. 2 shows ORCAD photodiode model. Every equation must be in general form, so that its parameters can be changed. The challenge was how to solve equation with the ORCAD tool and the analog behavior model (ABM) was the suitable solution. The photocurrent, dark current, noise current and the equivalent Junction capacitance represented the circuit model; the ABM helped us to use for each part of the model with the accepted function and behavior. The parameters which form the equation must be given to build the photodiode model and provide the accepted data with the real photodiode.

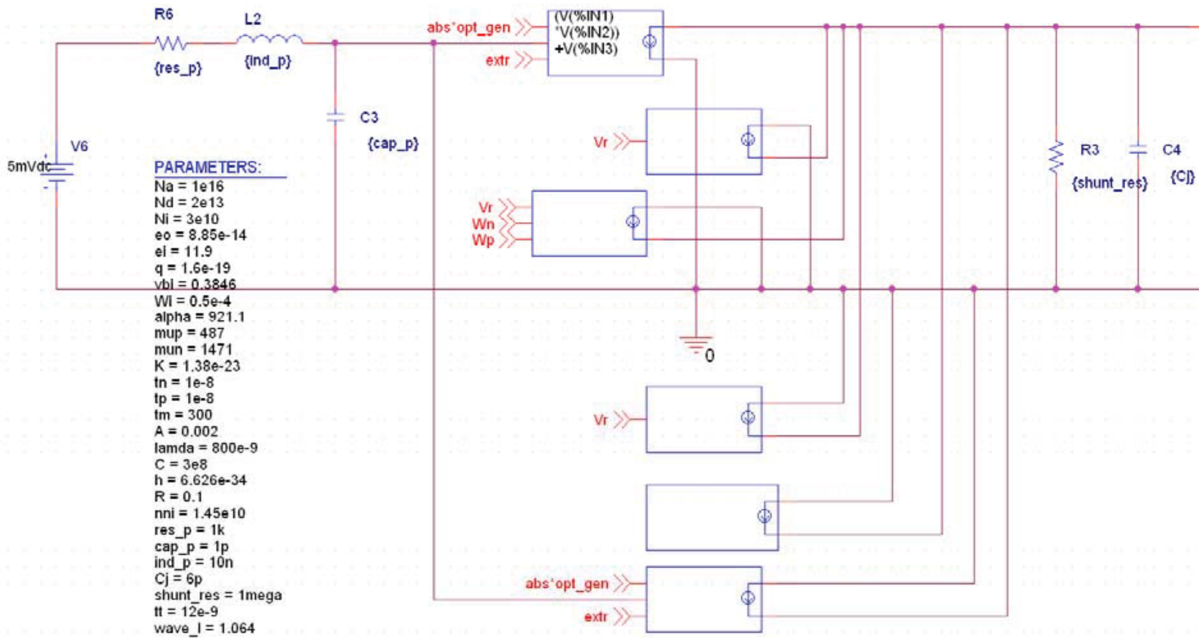

Fig. 2 ORCAD Photodiode model

The system is implemented in ATmega32 microcontroller along with a real-time graphical display of two servo motors, one for yaw and another for pitch angles. Also, multiple code selection with the selector switches is modeled and implemented to produce different pulse codes to increase the efficiency of the system.

A. Software Design

Two ATmega microcontrollers (MCU1/2) are used to simulate the laser pulse coding and tracking system [9]. MCU1 can be used to produce the laser codes as the simulator for laser designator, different codes can be used by changing the selector switches.

The MCU2 is used to decode the received pulse at the interrupt pin as input for simulation purpose. The MCU2 controls the two cases first, if the MCU1 and MCU2 are adjusted at the same codes, the system will detect the laser and the green LED will be ON, second if the MCU1 is adjusted at specific code different from the code on MCU2, the system will not detect the laser code and the green LED will be OFF and red LED will be ON.

For simulation purpose, we used two switches to control the codes from the MCU1/2 by changing the switches we have different PRF codes at the designator and the seeker.

B. Code Algorithm

The interrupt mode is the key of the programming techniques. Fig. 3 shows flow chart for PRF generation.

TABLE I
Communication Protocol between Switches and Controller

Octal switches	Terminal display	Function
(1,1)	50ms	ATmega Pin 18,19
(1,2)	50.800ms	ATmega Pin 18,19
(1,3)	51.600 ms	ATmega Pin 18,19
(1,4)	52.200 ms	ATmega Pin 18,19
…………	…………	…………
…………	…………	…………
(8,8)	100.800ms	ATmega Pin 18,19

Fig. 4 shows the flow chart for decoder and information detection for detecting PRF. The system is initialized and locks at 20 Hz. Then, Timer1 interrupt is low priority interrupt and all other interrupts' priorities are set at high priority. Signal from the MCU1 comes at interrupt I_0 at pin 16. It keeps on measuring the time between two pulses and calculates frequency. Time period is measure by Timer1.

Timer 1 prescalar is set to 1:64, which prevents the timer overflow in low PRFs measurement. The TIMER used to generate the clock for the system, each clock time is 4usec.

OCR1A= 90000/4=22500=0x57E4-1=0x57E3.

The following C code statements are used to calculate PRF:

- timer value = (TMR1H*256 + TMR1L);
- time period = (timer value /312500);
- frequency = (1/ (time period));
- TIMER1H is high byte register;
- TIMER1L is low byte register [9].

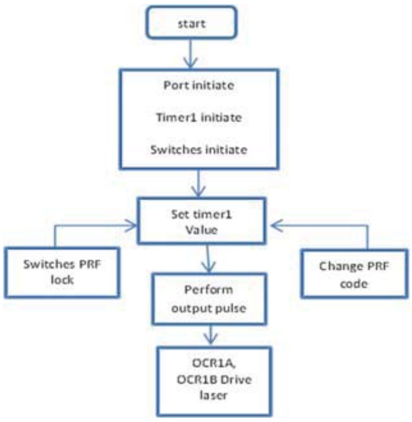

Fig. 3 Flow diagram for PRF generation

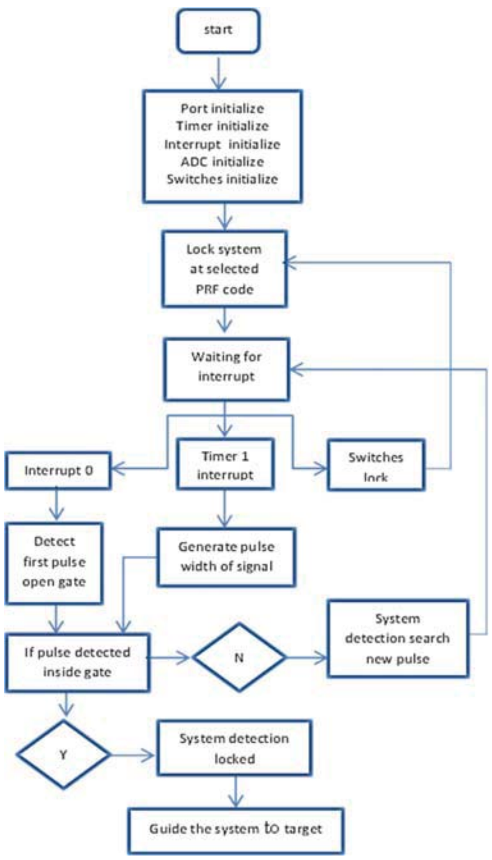

Fig. 4 Flow diagram for freq. detection and information generation

If the received laser code on the seeker is the same as the code adjusted on the seeker, the green LED is ON, while the received laser code is different from the code adjusted on the seeker the green LED is OFF and the red LED is ON. Analog to digital conversion (ADC) interruption is used to convert input analog voltage to digital voltage and amplify it to -90° to +90° yaw/pitch servo motor gimbal angle. The weapon's line of travel and its longitudinal axis are defined as Yaw angle. The pitch angle is the angle between the horizontal plane and weapon's longitudinal axis [9]-[11].

TIMER1 use the interrupt to generate the gate with 30 µs width to decide the received code is the same as the adjusted code on the seeker or no. The number of overflows is decreasing by Timer1 1:64 pre-scaler.

A serial interrupt UART is used to display locked PRF, detected PRF, yaw/pitch angles, and locked PRF can be changed using code selector switches [9], [12].

The gate signal is put to enhance the performance of anti-jamming, by using switches to select the locked code at the seeker.

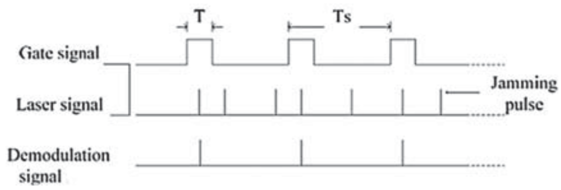

Fig. 5 The schematic diagram of the modulation waveform

As shown in Fig. 5, gate signal is generated equivalent to the signal of laser code which is transmitted by the laser designator. It has the same configuration as the laser radiation. The seeker decoder received the reflected laser radiation from the target including any other laser radiation. Based on the generated gate with specific pulse width, the system able to rejects jamming signal and locks real laser code. The wider the gate signal pulse width is, the higher interference occurs. So, to minimize the interference, jamming effect and increase the system sensitivity, the laser pulse gate must be as small as possible, only three input pulses are used to locked the laser code, and this is done based on the seeker module internal software code.

III. Hardware Implementation

Fig. 6 shows the general block diagram for laser spot position determination system containing laser source to simulate incident radiation , optical system to collimate incident radiation on the quadrant detector, the output of the quadrant detector is current in level of microampere, the electronic circuit for convert photocurrent to its corresponding volt and amplify to wanted level, microcontroller to make processing code/decode laser pulse based on PRF, and calculation on the output and with the help of computer shows the position of the spot on the quadrant detector, the mechanical system to adjust seeker at different angles and shows the corresponding output on the computer window [2], [13].

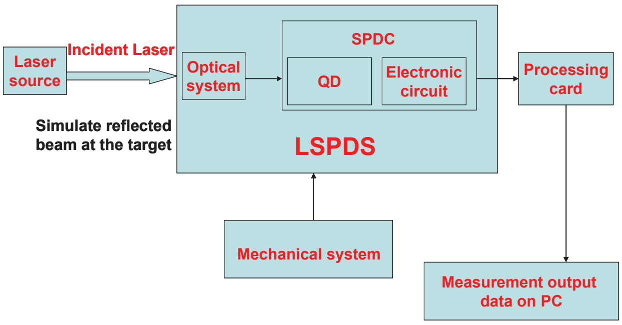

Fig. 6 The general block diagram for the laser spot position determination measurement

Fig. 7 shows the photograph of laser PCD device prototype. The hardware prototype was done and assembled to test laser PCD and recognize between different laser pulses. The system consists of QP50-6SD2which is used to bias the QD from ±4.5 V to ±18 V to put it in working mode, microcontroller programming Card working at +5 V, LD working with +5 V and MCU driver and selector switches.

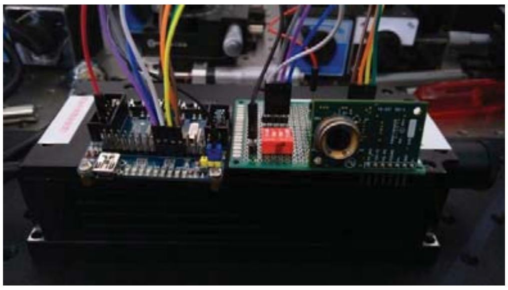

Fig. 7 The full system with laser pulses code detection device prototype

IV. Simulation and Results

Fig. 8 shows the schematic of one channel of the laser spot position determination Circuit [2], [3].

The full circuit diagram for the laser spot position determination. Starting with the photodiode model and including the preamplifier circuit, the gain circuit and the inverse amplifier and then the last stage of the laser spot position determination the ADC. The analogue signal output from each section of the 4-quadrant detector is to be read from the microcontroller to make the processing on the signal and provide X and Y position of the laser spot [2], [3].

Figure (9, 10) shows the laser spot with the quadrant detector when the laser spot at the center of the quadrant detector. Starting with the spot position at the center of the quadrant detector in this case the illuminated areas of the four photodiode are the same, then the represented value for the incident radiation is the same for the four photodiodes, the output of the four photodiode after the amplifier the output is the same due to the incident radiation on the four photodiode is the same, the output value of X and Y for this condition X=Y=0 due to spot center with the detector center.

Proteus virtual software modeling system (VSM) is commonly used in electronic simulation purpose [14], [17]. Its spatial features include the availability of simulating microcontroller and components, helps to test the full system virtually before making the final project implementation. Using Proteus frequency, Transient analysis tool, and width of different waveforms and signals can be analyzed with very high accuracy and precision.

The model of pulsed laser in a simulated environment. For this purpose, ATmega32 microcontroller used to generates pulses with different PRF of wavelengths according to used code select switches [19]-[20]. From Fig. 11, the pulsed laser model output microcontroller at PIN 18,19.

From Fig. 11, the full system of laser pulse model, laser receiver model, indicator LED for the system lock/not lock the target, the RED LED is on when the system not lock the target and the system starts to search again.

The GREEN LED is ON, when the system locked the laser.

Now different scenarios can be implemented depending on the locked PRF code at the receiver and locked code on the laser pulsed model. The different number of codes can be switched; the system is tested for two PRFs, 10 Hz and 10.8 Hz. Therefore, four different cases are studied for simulation purposes [18]-[20].

One of the cases is when detected frequency at interrupt pin and system is locked at 10 Hz. As locked PRF are equals, so the green LED is ON, as shown in Fig. 11. Similarly, in the second case, if the receiver switches select to code 2, so it becomes locked on 10.8 Hz, and the green LED switches OFF and red LED switched ON.

In the third case, if the select switch is now 10.8 Hz and hence detected PRF and locked PRF both become 10.8 Hz, and status green LED is ON and red LED is OFF.

In the last case, if we select switch on the receiver to locked at 10 Hz. Now, detected PRF is 10 Hz and locked PRF is 10.8 Hz. so both codes are different, the the green LED is OFF and red LED is is ON.

Fig. 11 shows the proteus virtual terminal output with different inputs from selected switches. When select switch is '1' at both designator and seeker, it shows the value of detected/locks system to 10 Hz. When selecting different code, the system forgets the target and starts to search again.

In the case where the system locked the target, gives permission to process data and makes a position calculation to detect laser center of the reflected beam, and then sends data through OCR1A, B data to move servomotor YAW/PITCh in order to word the target.

TABLE II
PRF Code Compatibility Tests

PRF code setting on designator(ms)	PRF code setting on seeker(ms)	System locked status
50	50	System locked
50.800	50.800	System locked
51.600	51.600	System locked
52.200	52.200	System locked
…………	…………	…………
…………	…………	…………
100.800	100.800	System locked

TABLE III
PRF CODE REJECTION TESTS

PRF code setting on designator(ms)	PRF code setting on seeker(ms)	System locked status
50	60	Searching mode
50.800	70.800	Searching mode
51.600	91.600	Searching mode
52.200	51.600	Searching mode
…………	…………	…………
…………	…………	…………
100.800	50.800	Searching mode

Table II shows the PRF computability test for the system including laser designator model with laser seeker model.

Different PRF codes were programmed in the laser seeker and the laser designator device using selector switches which are used to change code with different code outputs according to the table test requirements. We can show the compatibility between two models with the same values [9].

Table III shows the PRF rejection test for the system including laser designator model with laser seeker model. We can show that there is no compatibility between two models with different values [9], [20].

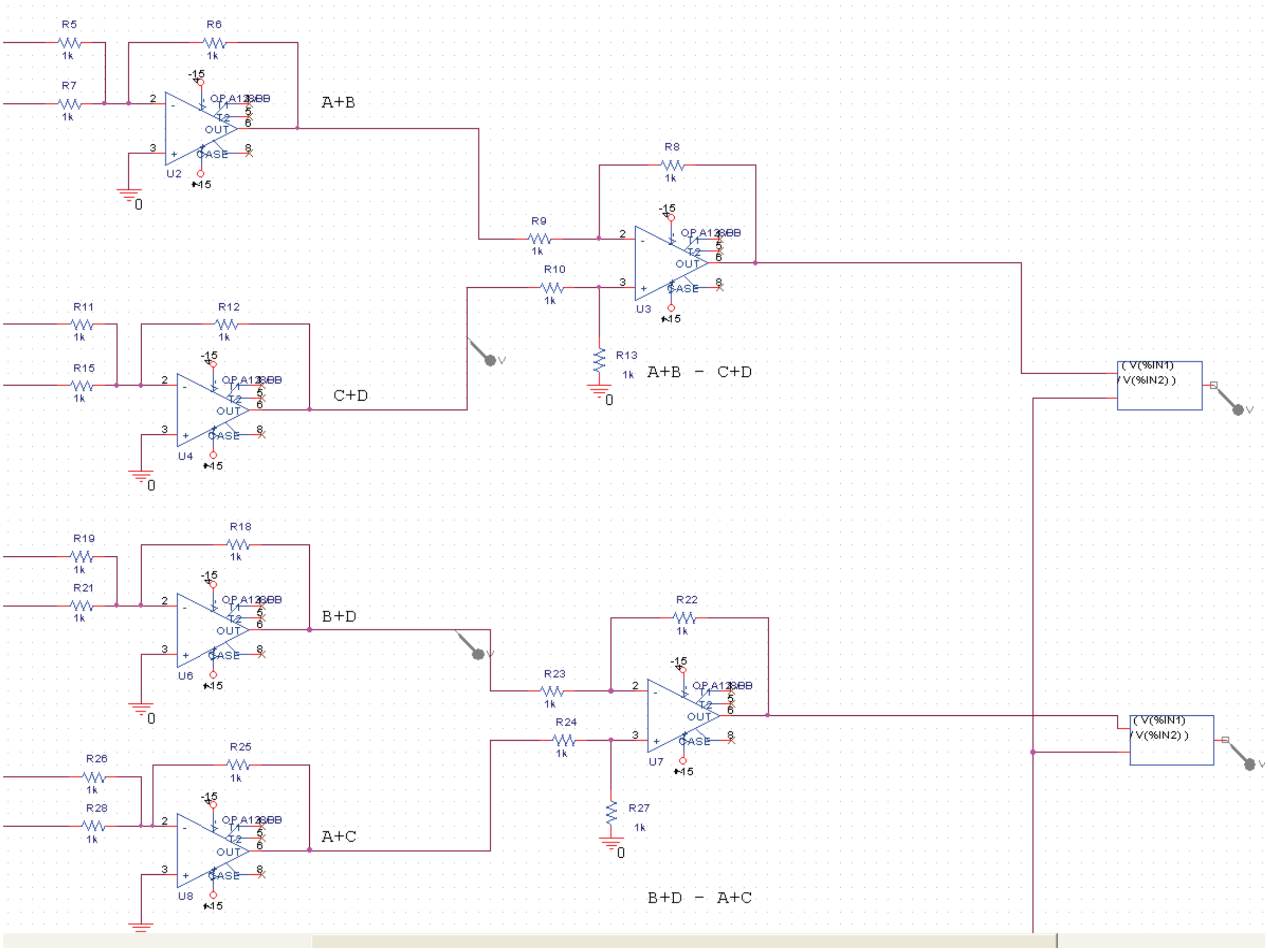

Fig. 8 one channel of the laser spot position determination circuit

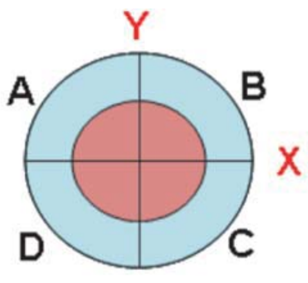

Fig. 9 Laser spot position at the center of QD and the circuit output signal

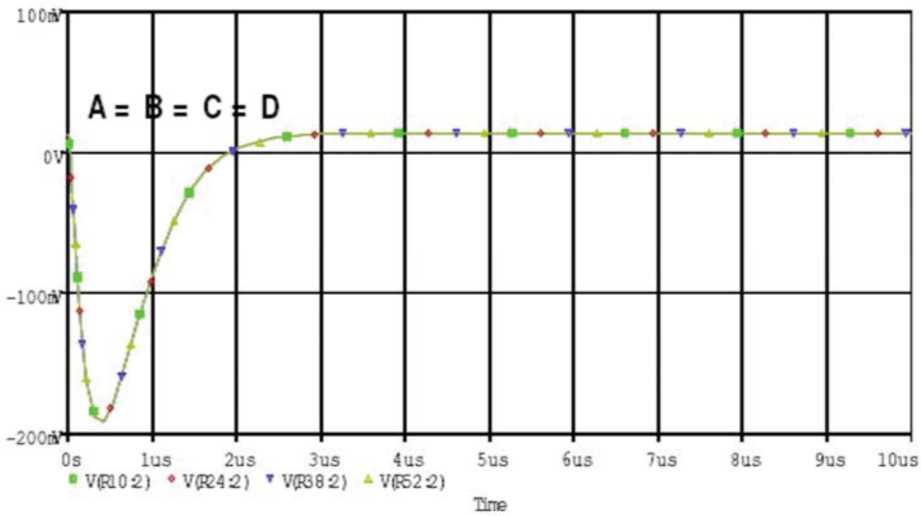

Fig. 10 four-photodiode signal after amplifier.

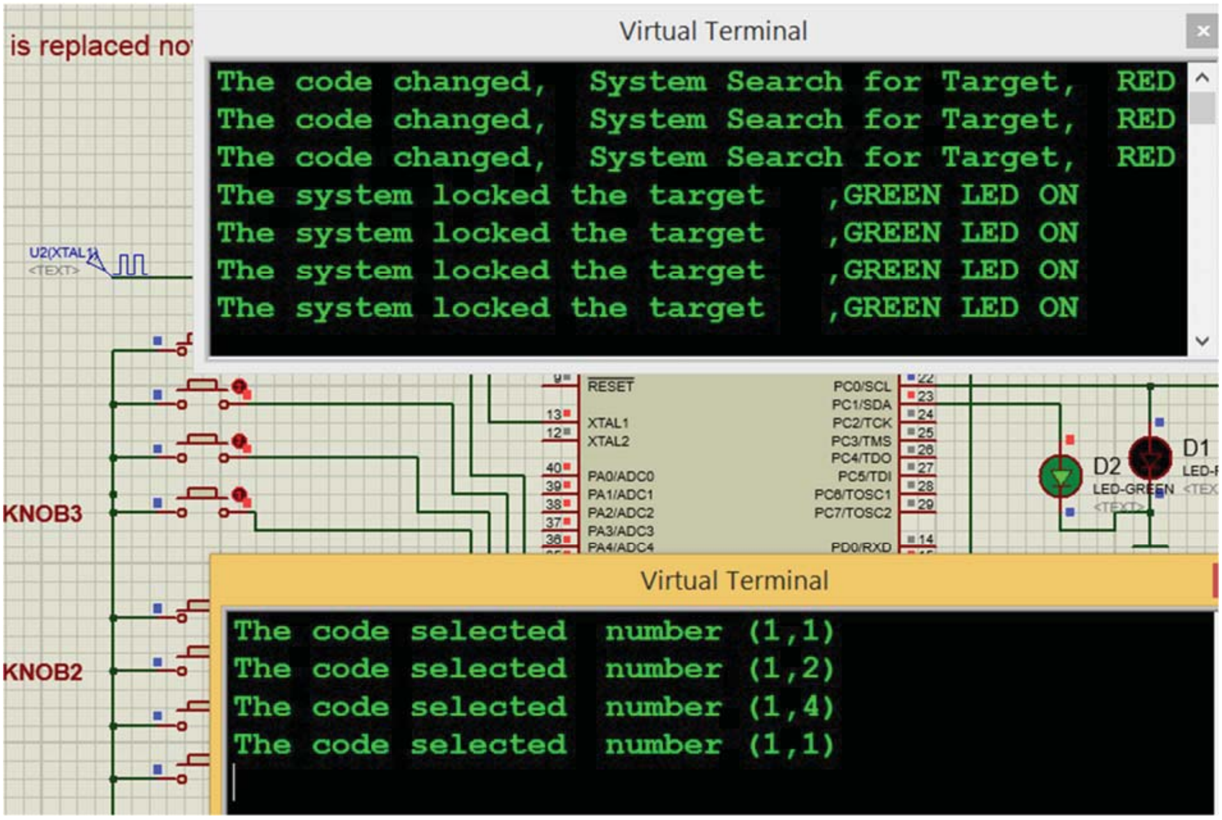

Fig. 11 The virtual terminal output with different inputs

V. Conclusion

In this paper photodiode model was implemented in ORCAD pspise tool, the validation of the model using a proposed setup was performed, a good agreement was achieved between the measured and simulated results.

Laser pulse code PCD system is developed using PRF Code. Based on the detection of a true code. Under different situations, the simulated results are obtained depending upon the locked PRF, detected PRF and switch selector commands given. We have status green LED ON to distinguish true pulse and red LED ON in the false pulse. Also, we get real-time output and input data for the yaw/pitch angle of the servo motor. The system is tested and simulated for the system PRF code compatibility, and rejection. Mainly test the PRF code compatibility of the seekers.

Acknowledgment

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