To the Graduate Council:

I am submitting herewith a thesis written by Jinliang Ren entitled "A Laser-Based Triggering System for Remote Actuation of Tractor-Mounted Instrumentation." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Agricultural Mechanization.

Fred D. Tompkins, Major Professor

We have read this thesis
and recommend its acceptance:

Accepted for the Council:

Vice Provost
and Dean of The Graduate School

A LASER-BASED TRIGGERING SYSTEM FOR REMOTE ACTUATION OF TRACTOR-MOUNTED INSTRUMENTATION

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Jinliang Ren

December 1988

AG-VET-MED.
Thesis
88
.R352

ACKNOWLEDGMENTS

The author wishes to express sincere appreciation to Dr. Fred D. Tompkins, major professor and chairperson of the graduate committee. His guidance and support were helpful throughout the research project and graduate program.

Appreciation is also extended to Dr. Robert S. Freeland, committee member, who provided helpful ideas and direction for the project.

The author is also appreciative of Dr. Luther R. Wilhelm, who served as a committee member and provided excellent classroom instruction and helpful assistance on the project.

Special recognition is given to Mr. Tom E. Droz. His technical skills and expertise allowed the project to be finished on schedule.

Finally, gratitude is expressed to Mr. Paul W. Elliott and Mr. Edgar O. Graves for their assistance in the construction of system equipment.

ABSTRACT

Instrumented tractors equipped with data acquisition systems developed in the last 10 years allow measurement of many vehicle and implement operational parameters. However, some systems lack the capability to initiate and terminate data acquisition precisely at predetermined points as the tractor is operated through the field. Results of previous experiments have indicated that measurement errors associated with manually actuating the data acquisition instrumentation can be considerable. Thus, a laser-based triggering device was developed to allow automatic remote actuation, both initiation and termination of data acquisition, of a tractor-mounted instrumentation system as a test vehicle was operated back and forth over a field plot, typically 60 m in length.

The triggering device consists of three subsystems: a laser emitting unit, a laser receiving unit, and an interfacing unit. Two 5-mW helium-neon lasers are used to provide precise reference lines for the system. A photodiode in the laser receiver is used as the sensing element. An optical filter included in the receiver package eliminates much of the influence of sunlight.

Two alternative triggering prototypes were designed. In the final system, laser light is continuously detected at the laser receiving unit. When the moving vehicle interrupts the laser beam, a radio transmitter in the laser receiving unit is actuated. Signals generated by the transmitter are used to excite a radio receiver designed to be mounted on the instrumented vehicle. The radio

receiver then initiates or terminates, as appropriate, the data acquisition process. Laboratory tests indicate that the triggering system was able to repeatedly time events with a precision of 0.01 second.

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CHAPTER I

INTRODUCTION

I. BACKGROUND AND STATEMENT OF THE PROBLEM

Automatic control systems are being increasingly used in both industry and agriculture. New control techniques which have been successfully employed in industrial applications are now being introduced into various agricultural areas. With increased use of computer and other new technologies in agriculture, farm tractors equipped with computer-based instrumentation have become popular in agricultural research. For instance, at the University of Tennessee, a 75-pto kW agricultural tractor was outfitted with a microcomputer-based data acquisition system for monitoring energy inputs to implements powered by the tractor (Hart, 1982). This microcomputer-aided instrumentation can be used to precisely evaluate performance of farm tractors and machinery. One version of the Tennessee instrumented tractor is shown schematically in Figure 1 (Freeland, 1985).

Many agricultural machinery manufacturers and universities have expended considerable effort in investigating potential uses for and in applying electronics to meet particular needs of specific agricultural operations. Since many agricultural researchers have been widely applying new electronic technologies to investigations of tractor performance, addition of automatic control to the monitoring

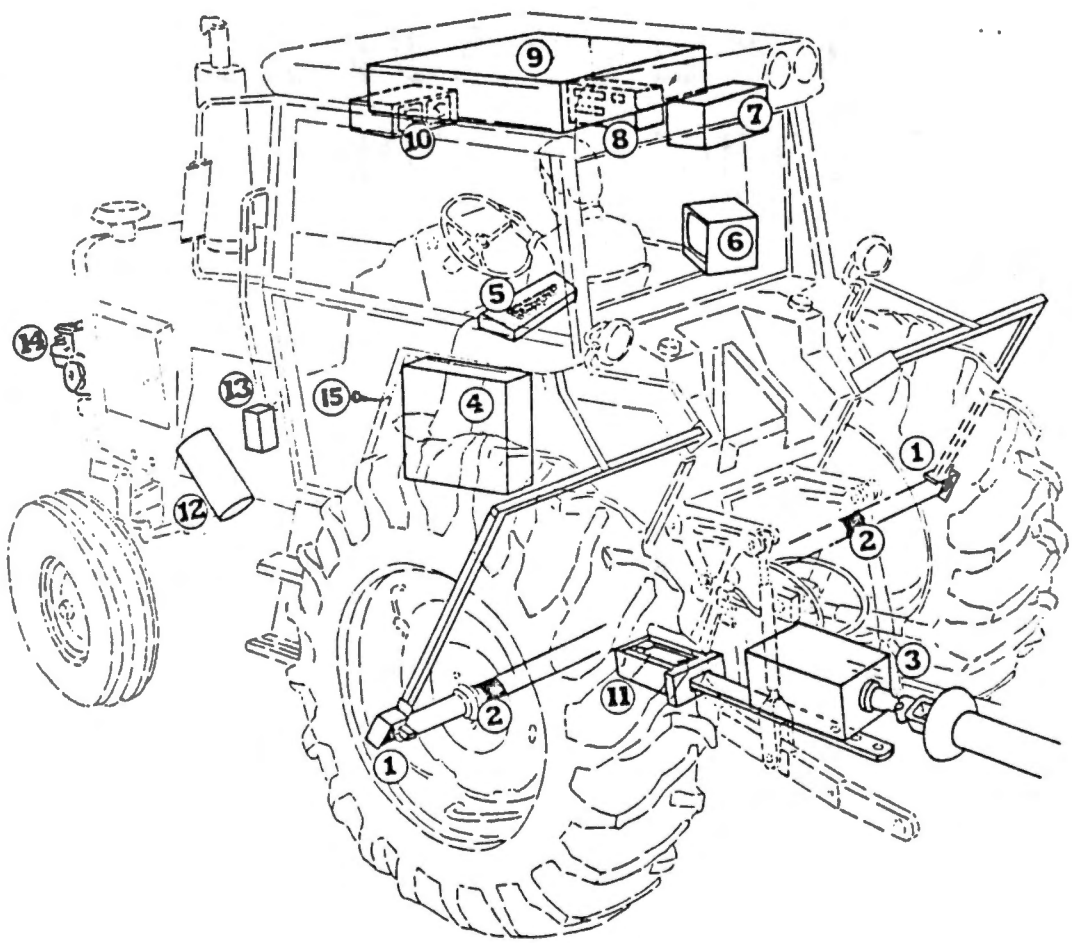


Figure 1. Instrumented tractor equipped with a microcomputer-based data acquisition system for measuring energy requirements of implements (Freeland, 1985).

system appears to be a logical next step in obtaining precise data and automated operation.

Many researchers have contributed to the improvement of components making up tractor-mounted data acquisition system, and many advanced techniques have been adapted to make the whole system more automatic and to improve its accuracy. For example, the commercial availability of radar sensors has enabled the measuring system to determine ground speed with far greater accuracy than with more traditional methods (Potter, 1986).

A fully instrumented tractor is capable of automatically collecting and recording parameters such as drawbar power, fuel consumption, and ground speed during actual field operation. However, data acquisition and handling may not be fully automated. For example, in tests by Tompkins et al. (1985), the data acquisition system was manually actuated as the tractor passed markers defining the beginning and the ending points of a measured test course. This manual instrumentation actuation was performed from the operator's platform. The operator needed to estimate the vehicle position and initiate the process by inputs at the keyboard (Tompkins and Wilhelm, 1982). Obviously, this method of initiating and terminating tests was not ideal in terms of accuracy for measuring distance traveled and travel time. Consequently, the recorded parameters could not be considered precise enough for certain evaluations. To improve the data acquisition process, a precision system is required for initiating and terminating field test runs.

II. OBJECTIVES

The primary objective of this project is to develop a laser-based triggering system for remotely actuating electronic instrumentation. This system will be applied on a tractor-mounted instrumentation system to automatically start and stop the data acquisition process at the beginning and at the end of a 60-m field plot. In addition, this triggering system will allow the tractor data acquisition system to precisely monitor the operational parameters, especially ground speed, over a finite distance in the field. Specific objectives of the study are to:

1. Design and construct a laser-based triggering system.
2. Test and evaluate triggering system performance.

CHAPTER II

LITERATURE REVIEW

I. EVALUATING TRACTOR AND IMPLEMENT OPERATIONAL PARAMETERS

Instrumented tractors equipped with data acquisition systems have been applied to monitor energy inputs to various implements operated over a range of different soil conditions. Specific measurement parameters obtained from field test data have included ground speed, drawbar pull, drawbar power, drive wheel slip, fuel consumption per unit time, and fuel consumption per unit area. These parameter values were actually analytically determined from recorded field test data.

There are many types of measurements taken by various vehicle-mounted monitoring systems, but six typical measurements are basic to evaluating several fundamental operational parameters:

1. Time,
2. Surface distance,
3. Implement draft,
4. Fuel consumption,
5. Drive wheel rotation, and
6. Drive wheel axle torque.

From these measurements, several parameters describing machine performance in the field can be analytically determined.

Ground Speed

Ground speed is computed based upon the time required to travel a pre-designated distance in the field with an operating implement. The typical length of the test field used by Hart (1982) was 60 m. For many agricultural situations, instantaneous ground speed is difficult to measure. Thus, average ground speed is widely used. This average ground speed can be directly obtained from time interval and distance traveled measurements as indicated in the following expression:

$$GS = S / T$$

GS ---- ground speed

S ---- distance traveled

T ---- time duration.

Drawbar Pull

In several research studies, drawbar pull was acquired directly from readings obtained with a drawbar dynamometer (Hart, 1982). In more recent systems, implement draft measurements were obtained by using quick-attach, three-point hitch couplers (Freeland, 1985). Another common method for obtaining implement draft force has involved direct mounting of discreet strain gauge units on the drawbar (Freeland, 1985).

Drawbar Power

Drawbar power can be computed from values of drawbar pull and ground speed. The relationship is shown below:

$$DBP = GS * DP$$

DBP ---- drawbar power

DP ---- drawbar pull

GS ---- ground speed.

Drive Wheel Slip

Drive wheel slip was determined from measured drive wheel speed and actual ground speed. The equation used to express drive wheel slip is shown below:

$$DWL = [(DWS - GS) / DWS] * 100$$

DWL ---- drive wheel slip expressed as a percentage

DWS ---- effective circumferential speed of drive wheel

GS ---- actual ground speed.

Fuel Consumption

Fuel consumption per unit time was computed from the volume of fuel consumed during the period of vehicle operation through a measured distance. Fuel consumption could also be computed based upon values of ground speed, travel distance, and fuel consumed over the specified distance. Fuel consumption per unit time may be computed as follows:

$$FCT = (FC * GS) / S$$

FCT ---- fuel consumption per unit time

FC ---- fuel consumed over defined travel distance

GS ---- ground speed

S ---- distance traveled.

Fuel consumption per unit area was computed from the volume of fuel consumed during operation through the measured plot and effective

operating width of the implement, as indicated in the following expression:

$$FCA = FC / (S * W)$$

FCA ---- fuel consumption per unit area

FC ---- fuel consumed over defined travel distance

S ---- distance traveled

W ---- effective width of the implement.

All the parameters computed thus far have some relation to ground speed. Ground speed, in turn, can be computed based upon the time required to travel a pre-designated distance in the field. Thus, obtaining a relatively accurate value for ground speed is extremely important, since other parameters are derived based upon this value.

II. METHODS FOR MEASURING GROUND SPEED

Generally, three methods have been applied by researchers for measuring tractor and implement ground speed. One method involves measurement of the angular velocity of a wheel with known circumference. A second method requires that the time to travel a known distance be determined (Hart, 1982). In recent years, new technology has resulted in the introduction of novel devices to aid in obtaining true ground speed. By using radar or ultrasonic sensors mounted on a tractor, instantaneous ground speed of the moving vehicle can be determined (Freeland, 1985; Freeland et al., 1988). Mean value of ground speed could then be analytically computed for applications requiring average velocity.

Researchers have used a variety of techniques to obtain true ground speed. These specific techniques are based upon the general methods noted above.

Engine Speed and Gear Selection

A very common, as well as very crude, way to estimate ground speed was to use engine speed and gear selection (Freeland, 1985). By employing angular velocity or angular displacement sensors, ground speed could be easily computed using the following relationship:

$$GS = ES * TR * C$$

GS ---- ground speed

ES ---- engine speed

TR ---- total transmission ratio,

engine speed / drive wheel speed

C ---- drive wheel effective circumference.

The primary disadvantage of this method was that it did not take into account slip of the drive wheels.

Non-Driven Front Wheel

A second technique used in earlier research involved monitoring the rotational speed of a non-driven tractor front wheel to indicate ground speed (Hart, 1982). Rotational speed of the front wheel was measured either by magnetic proximity sensors or optical incremental encoders. Ground speed could be estimated by using this rotational speed and the effective rolling circumference of the front wheel.

However, this method ignored slippage of the non-powered front wheel. Green et al. (1985) conducted speed comparison tests to

determine relative differences between front-wheel sensing and clocked measurements. Travel speeds obtained by using the front wheel sensor were 4 to 15 percent less than timed speeds. In addition, a front wheel may slide on some surfaces and change in effective circumference as the weight of the tractor is transferred back and forth between the front and the rear wheels in response to draft force changes (Freeland, 1985).

Fifth Wheel

A third technique for determining true ground speed involved use of a free-rolling fifth wheel. Hart (1982) used this method to predict machine travel velocity. A magnetic sensor attached to the fifth wheel assembly produced an analog signal proportional to rotational speed of the ground-contacting wheel. Based upon the effective circumference and the angular velocity of the wheel, ground speed was calculated.

However, the fifth wheel slipped when operated on loose soil and/or rough surfaces. Depending upon surface condition, travel time based upon fifth wheel measurements could approach 20 percent less than values based upon theoretical times for the distance traveled (Freeland, 1985).

Since measurements of distance traveled based upon effective circumference of the fifth wheel were not accurate, Smith (1985) designed a fifth wheel equipped with a pointer. This pointer rotated with the wheel and lightly touched the surface as each wheel revolution was completed. The pointer marked the initial and end

points of any given revolution in the space outside the wheel track of the vehicle. Ground speed was then calculated based upon angular velocity indicated by the fifth wheel and distance traveled during one revolution of the wheel. Ground speed values reported were based upon averages of the measured distance observed per wheel rotation.

Radar Sensor

A radar sensing unit used by Freeland (1985) was an application of new technology to the problem of accurately measuring true ground speed. The radar sensor was mounted on the side of the vehicle at a location allowing an unobstructed view of the ground.

Operating on the principle of Doppler frequency shift, this radar sensor transmitted and received radio frequency. The measured frequency difference between signals sent to and those reflected from the ground surface was proportional to the ground speed of the vehicle (Freeland, 1985).

Ultrasonic sensors, based on the same operating principle, are presently being introduced to measure velocity of a moving object. This type of sensor has been widely used previously to measure distance from a point to an object. Freeland et al. (1988) have now mounted such an ultrasonic sensor on a lawn and garden tractor to measure true ground speed or forward vehicle velocity. A combined transmitter/receiver measures frequency shifts in emitted ultrasonic pulse trains reflected from the operating surface. The sensor generates a digital output frequency directly proportional to ground speed (Freeland et al., 1988).

III. PROBLEMS ENCOUNTERED IN MEASURING TRUE GROUND SPEED

Each of the first three techniques discussed above employed a ground-contacting wheel attached in some way to the moving vehicle to indicate actual ground speed. Use of the non-driven, free-rolling wheel was an attempt to eliminate the effect of wheel slippage. Even non-driven wheels were subject to some slip. As the soil type and surface condition were varied with ground-contacting wheels, the level of wheel slippage exhibited a marked effect on the accuracy of computed ground speed. Parameters subsequently computed using the erroneous ground speed values were themselves not reliable.

In comparing radar sensors to ground wheels, the radar sensing unit can indicate true ground speed with less error (Freeland, 1985). The radar sensing unit exhibited the least error over most surface conditions and speed ranges according to results of tests involving: (1) a front wheel sensor, (2) a fifth wheel arrangement, and (3) a radar sensor (Freeland, 1985). However, the radar sensor produced the most error in indicated speed when the vehicle was operated in tall weeds. Research has shown that the radar sensor is greatly affected by rapidly changing surface conditions (Freeland, 1985).

In most field tests using instrumented tractors, a stopwatch or computer clock has been used to determine the time required to travel through the test course. This time estimation was then used to compute average velocity over the test run and was considered to be the standard for comparison (Smith, 1985).

Grevis-James et al. (1983) designed a microcomputer-based data acquisition system. An operator controlled the data acquisition process. In field tests, a key was depressed when the vehicle passed each of two markers which defined the limits of the test course. The microcomputer measured the time required to travel this 30.5-m distance and computed average ground speed.

Significantly, the speed sensing strategies described above can not produce an accurate indication of true ground speed under all field conditions since the data acquisition system had to be initiated and terminated manually (Tompkins et al., 1985). The operator started and stopped the test by manipulating switches located near the tractor instrument panel (Bedri et al., 1981). Manual operation will doubtless result in measurement errors because an operator can not reasonably expect to start and stop system operation precisely at a designated location for each test run. Therefore, travel times measured by either a computer clock or a stopwatch using manual actuation may not be sufficiently reliable for use in some tests.

Manual actuation methods do not automatically control the system operation. Further, they increase the work load of the vehicle operator when field data are being collected during multiple test runs. A system to initiate data acquisition precisely at the designated starting point and then terminate data collection at precisely a specified distance down range would both improve the quality of measurements involving ground speed and free the tractor operator to concentrate on other tasks.

IV. LASER APPLICATIONS

Laser Applications in Agriculture

Laser technologies have been widely applied in many areas including agriculture. The most important property of laser light is that all of the waves are in phase (Bickert, 1966). All wave fronts of the light beam are perpendicular to their direction of propagation; the beam is very nearly parallel. Since a laser beam could provide a very precise reference line or plane, lasers were first introduced to agriculture in land leveling, laser plane, and automatic depth control systems.

Bass (1985), in his laser-to-laser land leveling system, used a laser transmitter, a receiver, and an automatic recorder to obtain land survey information. The transmitter was self-leveling and was mounted on either a tripod or a trailer located near the center of the area to be surveyed. The transmitter emitted a rotating helium-neon laser beam that was extremely accurate (±15 mm) for at least 300 m in one direction. The receiver was an automatic tracking set of photocells that detected the laser beam as the vehicle supporting the receiver moved about the field. Changes in land surface elevation were indicated by variations in electrical impulses as the vehicle moved from one survey point to another. Data values were stored in the recorder each time the vehicle crossed a survey point.

Fouss and Hamdy (1972) developed an automatic grade control system for a drain-tube plow machine. This system used a laser beam

projected from a portable tripod-mounted source as an elevation reference. The receiver was mounted on the machine. The laser beam was projected toward the drainage machine above and parallel to the proposed drain line. The receiver sensed the deviation from the beam. An on-board controller unit detected the changes in the receiver output and energized the solenoid of a hydraulic valve. The valve activated a hydraulic cylinder to correct the hitch point elevation, thereby controlling the plow depth automatically.

Goris (1984) introduced a height measurement device in his topographical survey system. The device involved three components: a laser transmitter, a laser receiver, and an electric master. The function of laser transmitter was to provide a reference point for height measurement. The reference was formed by rotating a laser beam through a fixed plane in space. The function of the laser receiver was to detect the presence of the laser beam and to determine where the reference plane was in space. The receiver then activated one of three control lines, above, below, or on grade. Three control signals were then used in a closed loop system to drive the mast up or down in order to keep the laser beam crossing the null point and to show the land height.

During recent years, lasers have been applied in data communications systems. Land and Allison (1987) designed a laser-based communications system to relay information from remote sensors to a central control unit. The system consisted of a low-power (5 mW) helium-neon laser, a single board computer, and a retro-reflector and

was designed to operate indoors or outdoors at distances of up to 600 m.

Mizrach et al. (1987) developed a field machinery guidance system using a scanning laser technique. A single rotating laser beam transmitter was mounted on a mast in a fixed position in the field. Four receivers were mounted on a rigid rectangular frame attached to the main tower of the multi-jointed mobile truss. Signals received were processed by a computer located on the vehicle. A computer program was developed to calculate location and orientation of the vehicle in the field and to guide and steer the machine.

Development of Laser Detection Systems

Manufacturers all over the world are currently producing various types of lasers, photodetectors, and optical components. For general applications, helium-neon lasers are the most widely used due to their reliability and low cost (Melles Griot, 1985).

Special photosensors for detection applications have been designed for high sensitivity and fast response at laser wavelengths. Photosensors with large effective sensing areas are also available for remote sensing systems. For location sensing and size measurement, array-type photosensors are simple and reliable.

Basic Elements of Photosensor

Silicon photosensors respond to the entire visible radiation range as well as to the near helium-neon laser wavelength range (Motorola Inc., 1983). Generally, there are three kinds of photosensors: photodiode, phototransistor, and photodarlington

(Figure 2). All of these silicon photosensors show the same basic radiation frequency response (Figure 3) which peaks in the near infrared radiation range (Motorola Inc., 1983).

Photodiode. Light radiation falling at the PN junction of a photodiode will generate hole-electron pairs which cause the carriers to move. This movement causes a current flow. The power density of the radiation (measured in mW/cm^2) determines the magnitude of the current flow (Motorola Inc., 1983).

Phototransistor. The phototransistor is a light radiation controlled transistor. The collector-base junction is enlarged and works as a reversed biased photodiode controlling the transistor. Collector current depends upon radiation density and the DC current gain of the transistor (Motorola Inc., 1983).

Photodarlington. A photodarlington works on the same principle as a phototransistor. The collector-base junction of the driver transistor is radiation sensitive and controls the driver transistor. The driver transistor, in turn, controls the following transistor. The Darlington configuration yields a high current gain which makes for a photodetector with very high light sensitivity and fast response (Motorola Inc., 1983).

Recent developments in detection technology have led to larger and more complex circuit integration. Photodetectors incorporating Schmitt trigger logic outputs are becoming increasingly popular in

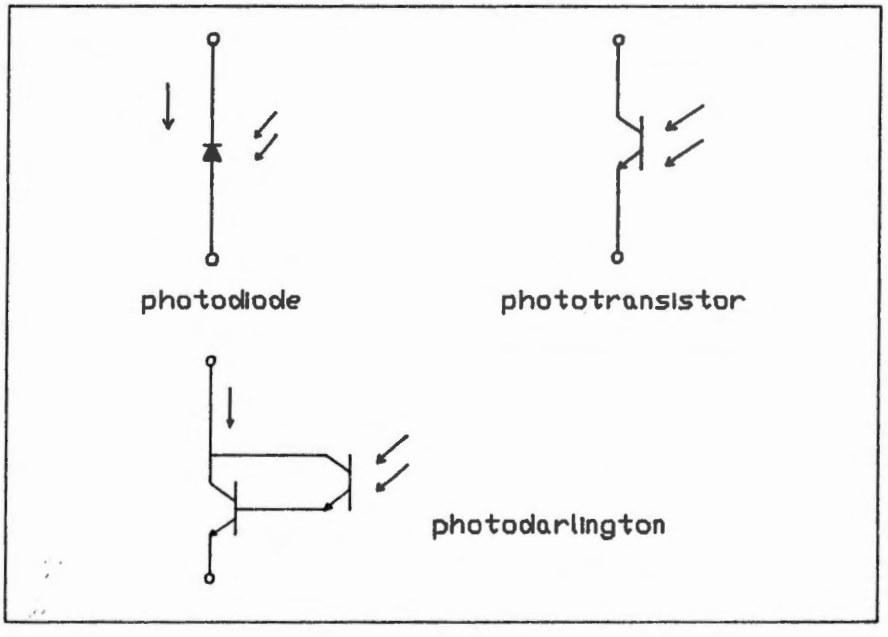


Figure 2. Working principle of photosensors: photodiode, phototransistor, and photodarlington.

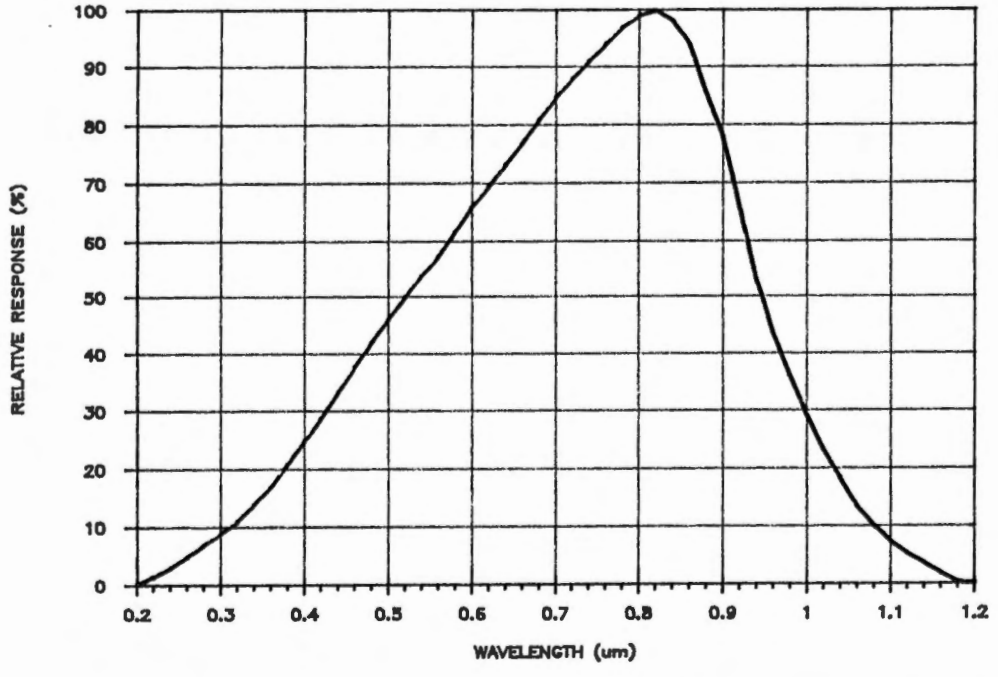


Figure 3. Typical spectral response curve for all silicon photosensors.

applications requiring very high speed, hysteresis for noise immunity, and logic level outputs (EG&G Photon Devices, 1987).

Photodiodes are being applied in one of two modes. When the PN junction is illuminated and a connection is made to both sides of the junction, a current will flow during the period of illumination. This is called the photovoltaic mode (PV). In this case, there is no external bias applied (EG&G Photon Devices, 1987).

If an external bias is applied in the reverse direction at the PN junction, current will also flow under illumination. The current generated is composed of both photoinduced current and reverse leakage (dark) current. Reverse leakage current will remain constant for fixed bias and fixed temperature conditions. This is called the photoconductive (PC) mode (EG&G Photon Devices, 1987).

The design decision to use a PV or a PC photodiode is predicated primarily on the frequency response requirements of the given application. For fast response applications, the photoconductive mode is recommended (EG&G Photon Devices, 1987).

Applications with Optical Sensing Devices

For laser applications in agricultural areas, photodiodes are widely used as sensing elements in detection systems. For example, a Bell and Howell type 529 photodiode optical detector was used in a laser-based communication system to detect a laser beam. This model was chosen due to its high sensitivity at the helium-neon laser characteristic wavelength (632.8 nm) and its ease of implementation (Land and Allison, 1987). In another laser application, a receiver

consisted of a silicon photo-voltaic element built into a cylindrical structure to sense the laser light (Mizrach et al., 1987). In a field machinery guidance system with laser scanning, photodiodes were used as photodetector elements to sense the reference laser light (Shmulevich et al., 1987). For data communication systems, phototransistors or photodarlingtons with high sensitivity were used in receiver circuits to sense light from light-emitting diodes (Motorola Inc., 1984).

Photocells have also been widely used in laser detection systems which did not require fast response. In a topographical survey system, the laser receiver was constructed using multiple photovoltaic cells to detect the laser beam when it crossed the photocells (Goris, 1984). In a laser-based land leveling system, the receiver consisted of a series of silicon photocells arranged to sense the laser plane position as it struck the receiver (Dedrick, 1979).

Fiber optical signal transmission has been used increasingly in systems involving optical sensing. When data are transmitted over an optical waveguide, it is considered fiber optical transmission. The most common optical waveguide materials are plastic and glass (Freeland et al., 1987).

Fiber optical technology has aided several researchers. Koepf and Markey (1984) developed a two-dimensional fiber array for obtaining parallel readout of information in the output plane of a automated microposition measurement system. A very high packing density was obtained by using optical fibers as lightguides between the light source and the photodetectors. Fiber optical technology

offers promising solutions to many data communication obstacles (Freeland et al., 1987). With development of laser applications, fiber optical systems can be applied for long-distance data communication.

In recent years, many manufacturers of optical components have designed and produced new products for special applications. These products can make optical system design simple, low-cost, and highly efficient. For example, the multi-mode fiber optical couplers produced by CANSTAR (1987) can be easily applied in data distribution or collection networks. Up to 64 fiber divisions can be accommodated. Tapered optical fibers produced by C Technologies Inc. (1986) can be used for applications in which the fiber radius needs to be expanded or condensed. These optical fibers can be used as passive optical components to alter the input and/or output divergence with regard to an optical fiber.

CHAPTER III

DESIGN OF TRIGGERING SYSTEM PROTOTYPES

I. TRIGGERING SYSTEM DESIGN CRITERIA

The first step in designing the triggering system was to search for an appropriate method to precisely initiate and terminate the data acquisition process at the beginning and end points of a field test course. Tractor-mounted instrumentation was to be started and stopped precisely at the end points of a field such that elapsed time could be accurately measured. Thus, a technique for identifying these end points was required.

In defining ground speed as distance per unit time, the average value of ground speed is the parameter actually sought. After laying out the field course, the critical step is to measure the exact travel time duration through the pre-designated test course. True ground speed then will be obtained based upon this time duration and travel distance.

A 60-m test plot length was assumed as typical. Thus, a specific triggering system was to be designed which would automatically start and stop data acquisition as the instrumented tractor passed the beginning and end points, respectively, in the test plot (Figure 4). If the data acquisition system was started and stopped in precise alignment with the end points, the computer clock would give an accurate and repeatable indication of travel time. Actual ground speed and other parameters which are functions of actual

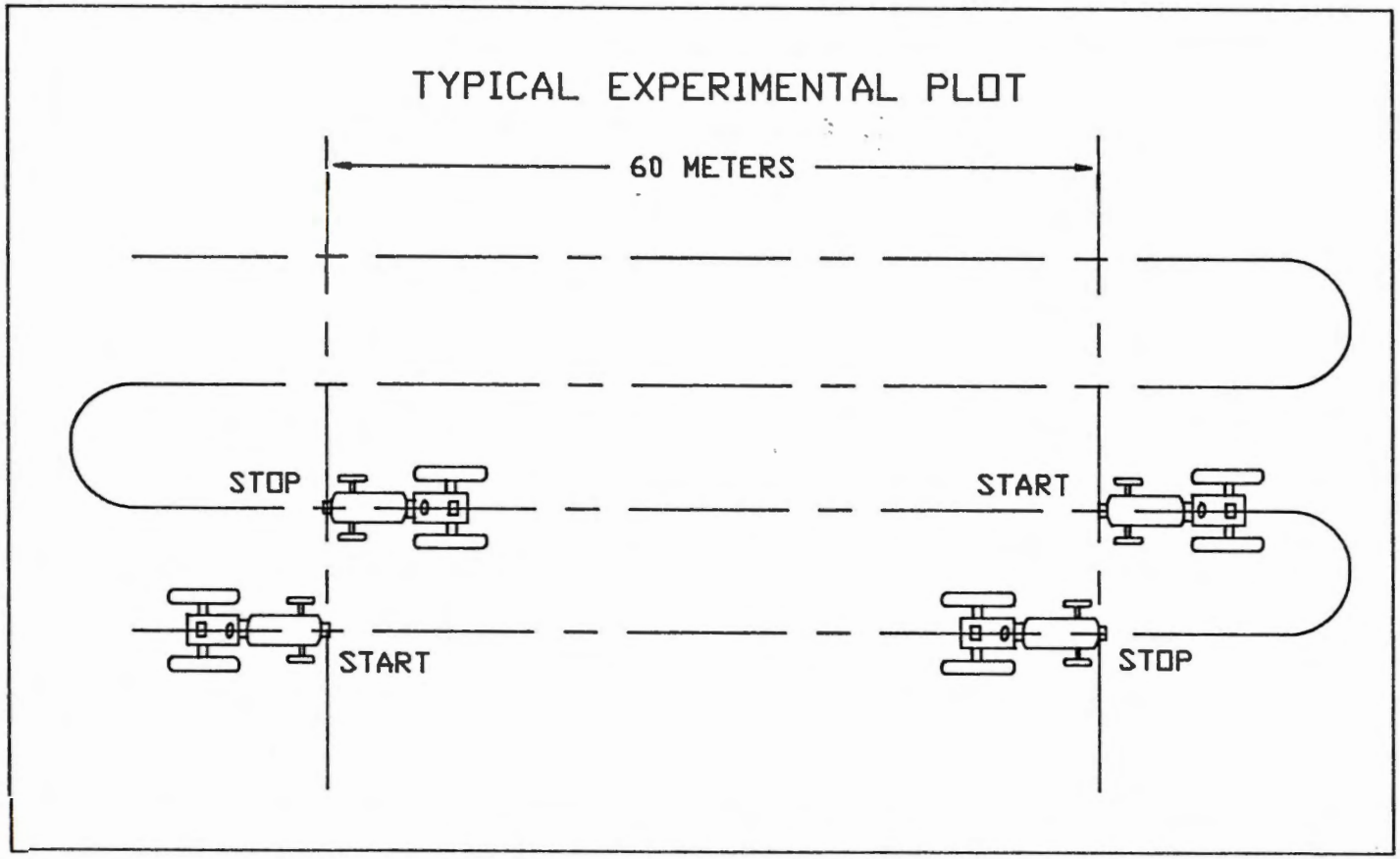


Figure 4. Schematic diagram of a typical test field layout which serves to define the triggering system design requirements. As the test vehicle enters the 60-m plot, data acquisition is initiated. When the vehicle reaches the end of the plot, data acquisition is terminated.

ground speed could be computed with greater confidence that they accurately describe actual tractor and implement performance.

II. EVALUATION OF POSSIBLE TRIGGERING SYSTEM ALTERNATIVES

Contacting Wire

Contacting switches or naked wires have been widely applied to start or stop a mechanical action. This method may be theoretically applied to this project. Naked wires can be buried underground or suspended across a field. A contacting switch is mounted on the tractor. When the moving tractor reaches the naked wire, the tractor-mounted switch will be activated. When the tractor loses contact with the naked wire, the switch will return to the off position. This on-and-off signal could be used to start and stop the data acquisition process. For tests requiring multiple passes, proper system response to a given on-off signal can be maintained with a microcomputer.

This contacting wire method is simple and inexpensive. However, such a system is not easy to construct and maintain in the field. Further, this system is easily affected by environment. This makes obtaining precise values difficult. Since operating implements such as tillage machinery always dig into the soil, the naked wires realistically can only be suspended. Keeping wires standing firmly is difficult. As a result, the contacting wire system can not be expected to produce reliable values. Thus, the method was deemed inappropriate for this data gathering application.

Radar and Ultrasonic Sensors

Radar and ultrasonic technologies have been applied to determine distance between objects. One of these radar or ultrasonic measuring systems could be mounted on the tractor to monitor the distance from the tractor to a marking post set at the side of the field (Figure 5). This distance between the moving vehicle and the marking post will be monitored constantly with the aid of a microcomputer. When the indicated distance is minimized, the computer will automatically start or stop data acquisition. Since all the measurement devices are installed on the tractor, the entire system could be easily set up for field operation within a short time.

However, this method may in actuality produce false messages which lead to incorrect actions because the tractor may not be operated in a straight line. Depending upon the terrain and surface operating conditions, the tractor may slightly sway to either side of the travel line while moving forward. Accurate and instant determination of when the tractor reaches the real starting or stopping line may be very difficult.

A variation of this method may eliminate some of this problem. Two marking posts could be set 60 m apart along the side of the field. The distance measuring system on the tractor could simultaneously monitor distances from both marking posts. When the sides (distances from the tractor to the two marking posts plus the distance between the two marking posts) construct a right triangle, the tractor is positioned precisely on either the starting or stopping line.

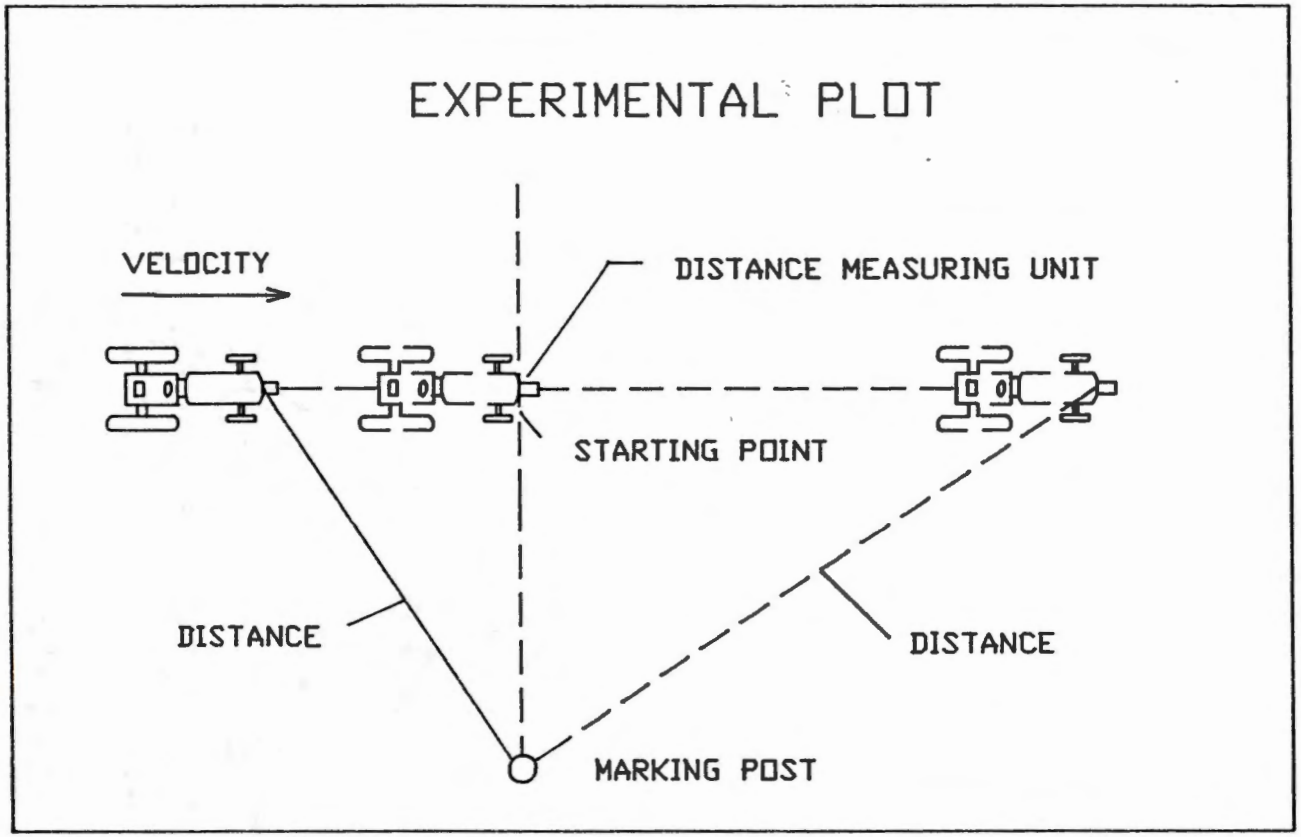


Figure 5. Operating principle of a distance measurement system using a radar or ultrasonic sensor as the triggering device. When distance from the vehicle-mounted sensor to the marking post, which represents the beginning or end of a 60-m plot is minimized, the data acquisition instrumentation is actuated.

Ultrasonic sensors may give false information because of poor direction sensing capabilities. With increases in working distance, this situation will worsen. Another disadvantage of using ultrasonic sensors is that response is slow. Since the tractor is moving, slow sensor response can result in considerable error.

In addition to the disadvantages noted, these systems involving geometric analysis are quite complex. Therefore, the precision requirement associated with this project can not be easily satisfied using such a system.

Laser Triggering Device

Laser control systems are now commercially available and are being widely used in agricultural research for precision measurement and control (Fouss and Hamdy, 1972). The principal advantage of a laser control system is its stability and precise direction property. This technology is commonly applied in non-contact control systems where the laser beam serves as a reference line or plane. Lasers are ideal tools for relative location sensing and control. Through proper design and adaptation, laser control systems can be used for both elevation and guidance sensing and control (Fouss and Hamdy, 1972).

In this project, laser beams can be used as precise reference lines which denote starting and stopping lines at the ends of the test plot. When the instrumented tractor equipped with a laser sensing device passes through this reference line, the laser sensing device can produce a signal to precisely start and stop the data acquisition process (Figure 6).

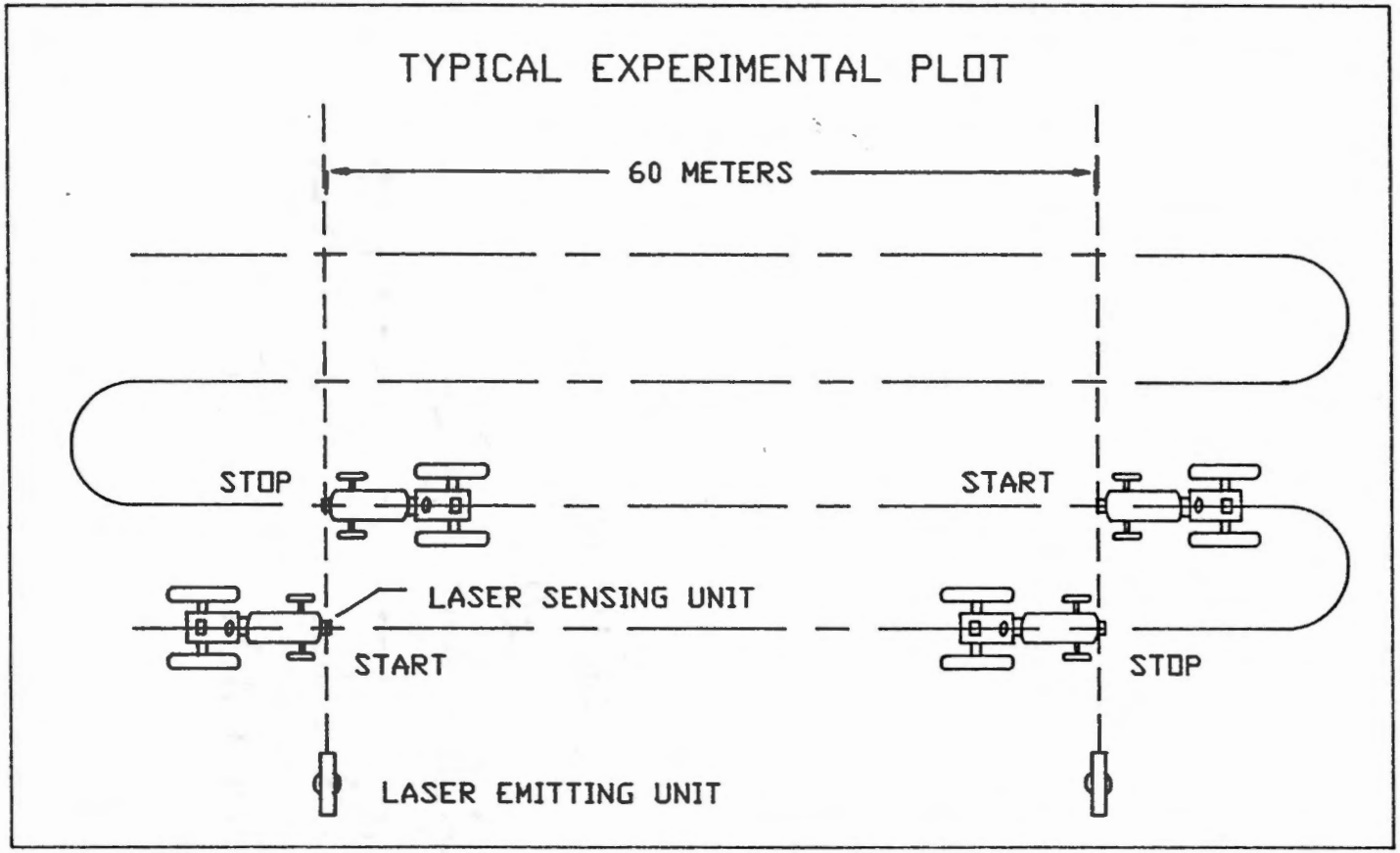


Figure 6. Operating principle of a laser triggering system with a laser receiver and an instrumentation interface unit mounted on the vehicle.

III. PROTOTYPE SYSTEM DESIGN

Laser Triggering System

Having considered the alternatives already discussed, the laser-based triggering system approach was finally selected for this project. In this triggering system, laser beams form reference lines marking the starting and the stopping points as the vehicle travels across the field. These lines are typically about 60 m apart.

The initial design approach includes mounting the laser receiver on the front of the tractor. When the tractor passes the laser beam, the tractor-mounted receiver will detect the laser light and generate a signal. In this case, the signal can be directly transmitted by wire to the computer mounted on the tractor to control operation of the data acquisition system. To effectively sense the laser light, an array-type receiver is required. Such a receiver would accommodate tractor motion in response to surface undulation and uneven terrain. The laser system consists of two primary working assemblies: a laser emitting unit and a laser receiving unit.

Laser Emitting Unit

Two self-contained helium-neon lasers with a beam output power of 5 mW and a characteristic wavelength of 632.8 nm were acquired. The units, produced by Melles Griot Inc., were to be set at the side of the field 60 m apart. Emitted beams would be parallel across the field. The lasers would stand about 1 m above ground level to avoid potential eye injury due to looking directly into the laser light.

These parallel beams were to be used as reference lines to indicate test starting and stopping points.

Diameter of the light beam at the emitter is 0.77 mm. Beam divergence is 1.0 mrad. This means that, with increased distance from the source, the light spot size (diameter of the light beam) will be 0.1 percent of the distance. For instance, at a distance of 100 m, the beam diameter will be 100 mm. For a wide experimental plot, this diverging laser beam may not provide ideal reference lines.

As the distance from the source increases, laser power density will dramatically decrease due to beam divergence. A beam expander is recommended for long-distance applications. The beam expander is able to expand the diameter of the laser beam and considerably reduce divergence of the beam. As a result, laser beam diameter and power density will remain nearly constant as distance from the source increases.

To aid in setting up and aiming the laser emitting unit, the laser head was mounted on the top of a standard builder's transit-level. The laser head and level were mounted on a standard surveying tripod (Figure 7). The tripod-mounted unit could be set up and adjusted in the field in a manner similar to that used with a surveying instrument alone.

The procedure for setting the laser emitters was as follows. The two tripod-mounted laser emitter units were first set 60 m apart at the side of the test field. Secondly, leveling screws on the instruments were adjusted to level the laser heads. The laser heads were directly pointed toward each other, and the angle indicated on

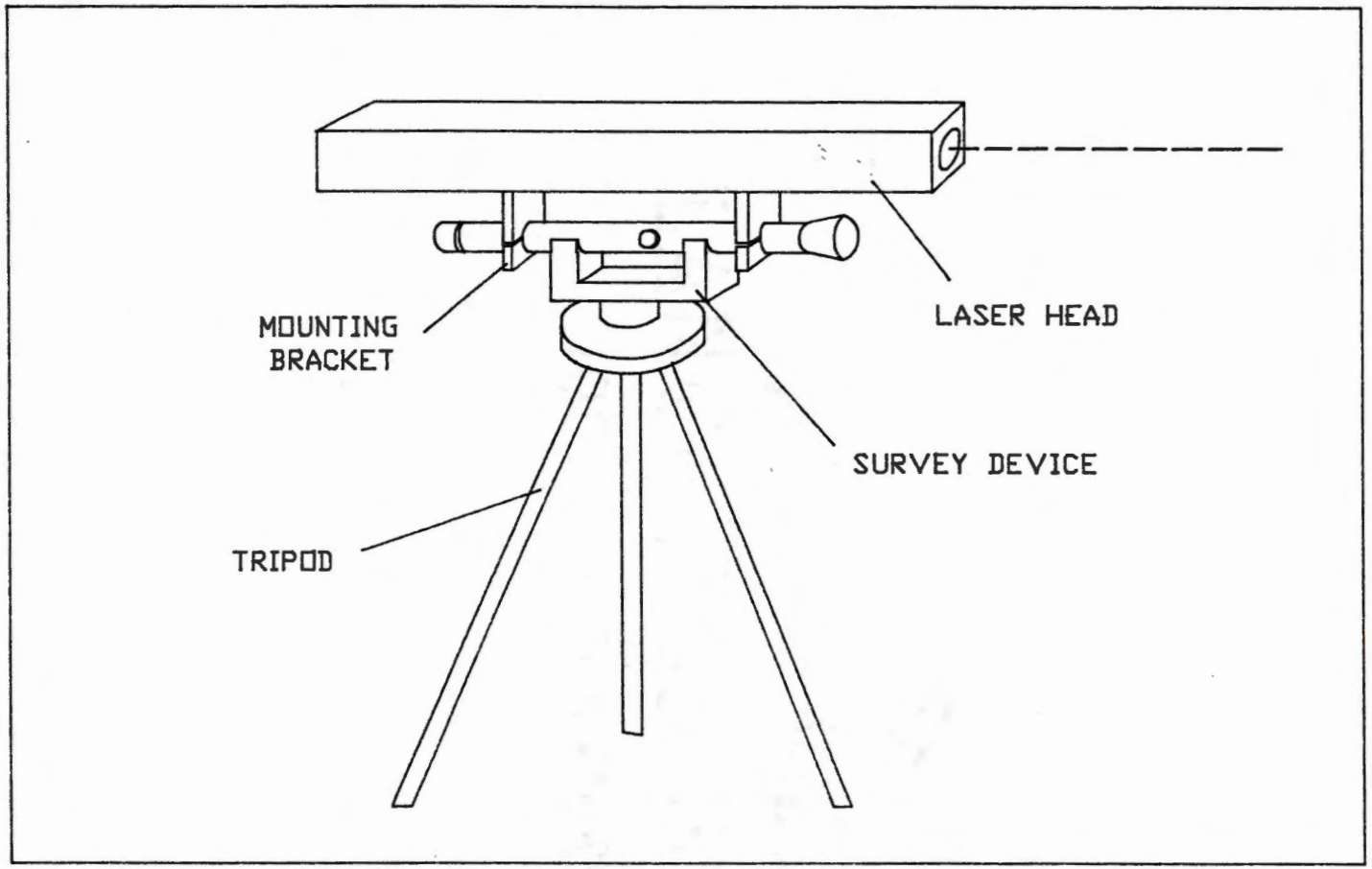


Figure 7. Laser emitting unit. The laser head is mounted on a survey instrument tripod to allow proper alignment in the field.

the horizontal circle of the instrument was recorded. The laser heads were then rotated exactly 90 degrees such that the beams were parallel and pointed in the same direction. The distance between the apparently parallel beams was checked at a point several meters down range from the emitting units. This check indicated that the above method of aiming the instruments was satisfactory for maintaining parallel beams. The mounting design was quite simple and low cost, and met the design requirements for precision and easy operation.

Power requirement of the laser emitter is 120 volts AC. In laboratory tests, power is taken directly from a standard 120-volt outlet. When operating in the field where the standard power source is not available, a portable AC power supply is required to drive the lasers. An AC generator is appropriate for this application. A battery and a DC/AC converter could also be used to power the lasers.

Laser Receiving Unit

Problems to Be Considered. Primarily, there were two problems to be considered in the receiver design:

1. Selection of appropriate components and properly configuring these components to distinguish between laser light and ambient sunlight, and
2. Fabrication of an inexpensive and simple device which could sense laser light admitted by the array-type receiver and then produce a signal to actuate the computer.

The laser receiver was to be designed to produce a TTL signal when the laser light was detected. This TTL signal could be used to actuate the data acquisition instrumentation.

Common photosensing elements used in a variety of photo-detection applications include photodiodes and phototransistors. In this project, an inexpensive MFOD72 phototransistor similar to that used in the data communication system described by Freeland et al. (1987) was initially selected as the sensing element. This photosensor had relative high sensitivity (70 percent of peak response) at a wavelength of 632.8 nm, and response time was less than 60 μs (Motorola, 1984).

The primary problem with this sensing unit was the influence of background sunlight. A simple sensing unit including a phototransistor and an amplifier transistor worked very well for detecting laser light in the laboratory. But outdoors, the intense sunlight caused the receiver to continuously indicate that light was being detected even when the receiver was not exposed to the laser light. A key to producing a successful design was to find a suitable method for eliminating or avoiding the influence of ambient sunlight. In other words, the sensing unit had to be able to distinguish between laser light and background light.

Methods for Reducing the Influence of Sunlight. Basically, four methods have been commonly used in laser applications to avoid the influence of direct sunlight. One application made use of long narrow shades to prevent direct and reflected sunlight from impinging

upon the photosensor. These shades were cardboard tubes placed over the detector housing (Land and Allison, 1987). Another application employed optical filters which allowed only radiation at a frequency near that of the laser to be passed to the detector.

A third method involved use of a differential amplifier circuit in the receiver to distinguish between laser light and sunlight. Upon detecting the laser light, an output signal could be generated. The fourth method of detecting the laser light was to project the laser beam at a constant frequency. The laser beam was mechanically "chopped" at a constant frequency, and an electronic bandpass filter was used in the receiver circuit to filter out all signals except those having a frequency in a narrow band around the constant frequency. This approach allowed the system to ignore light sources other than the signal created by the chopped laser beam (Fouss and Hamdy, 1972).

For best results, a combination of methods might be most appropriate. A laser line filter with a peak wavelength of 632.8 nm, the laser frequency, was selected to reduce the problem caused by ambient sunlight (Figure 8). This filter produced by ORIEL Corporation was specially designed to pass light in a very narrow frequency bandwidth and was considered ideal for use with a laser beam receiver in a strong white background (ORIEL Corporation, 1984).

Since sunlight has only a small portion of its total radiation with wavelengths in the narrow band characterizing the filter, the photosensor should only detect the relatively more intense laser

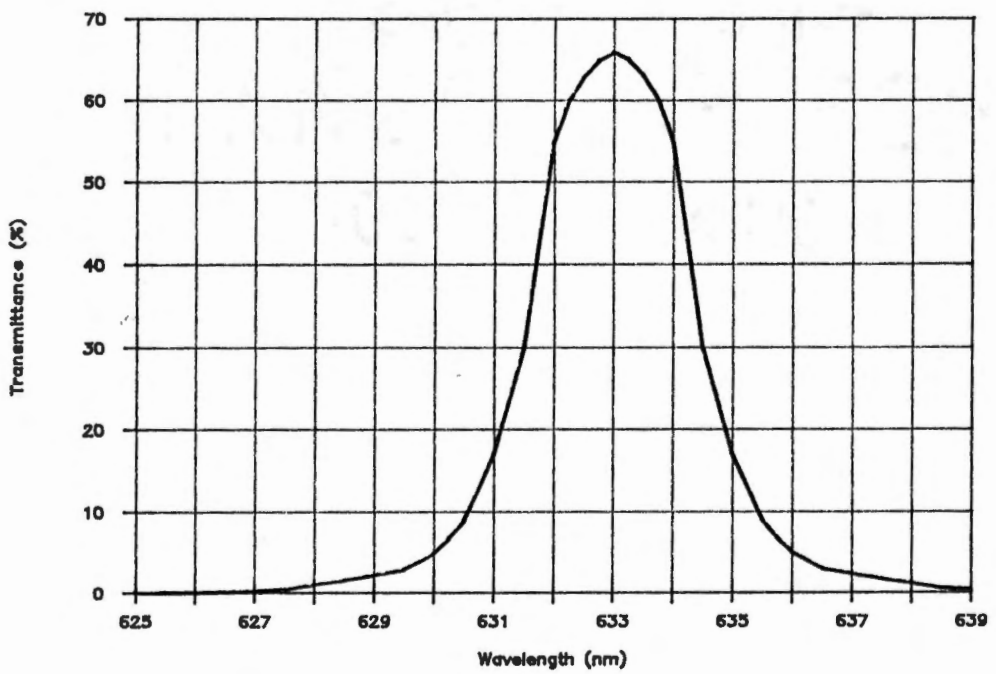


Figure 8. Transmission curve of the bandpass filter used with a helium-neon laser.

light. For improved results, a shade could be used to decrease exposure of the sensor to direct sunlight.

Effective Receiver. Since the tractor would not always be operated over absolutely smooth terrain, an array-type receiver was considered necessary to effectively detect the laser light in all conditions (Figure 9).

Under real operating conditions, no point on the moving vehicle would be expected to constantly remain in the plane created by the two laser beams. Thus, a simple sensor placed at a point on the tractor would not be practical for detecting the laser beams considering the range of field operating conditions encountered in tractor-implement testing.

In this field application, an array-type receiver was needed. The array would be oriented vertically and positioned on the front of the tractor. This vertical orientation of an elongated receiver would greatly extend the capability of the sensor to detect the laser beams even though some changes in sensor elevation would occur as the tractor was moved across the test course.

Fiber Array Applications. To reduce the number of photosensors required in the array-type receiver system, a fiber array was proposed for use as waveguides to transfer the laser light to a photosensor. In this case, the 632.8-nm wavelength interference filter could be placed in front of a single photosensor to eliminate the influence of sunlight. The concept is illustrated in Figure 10.

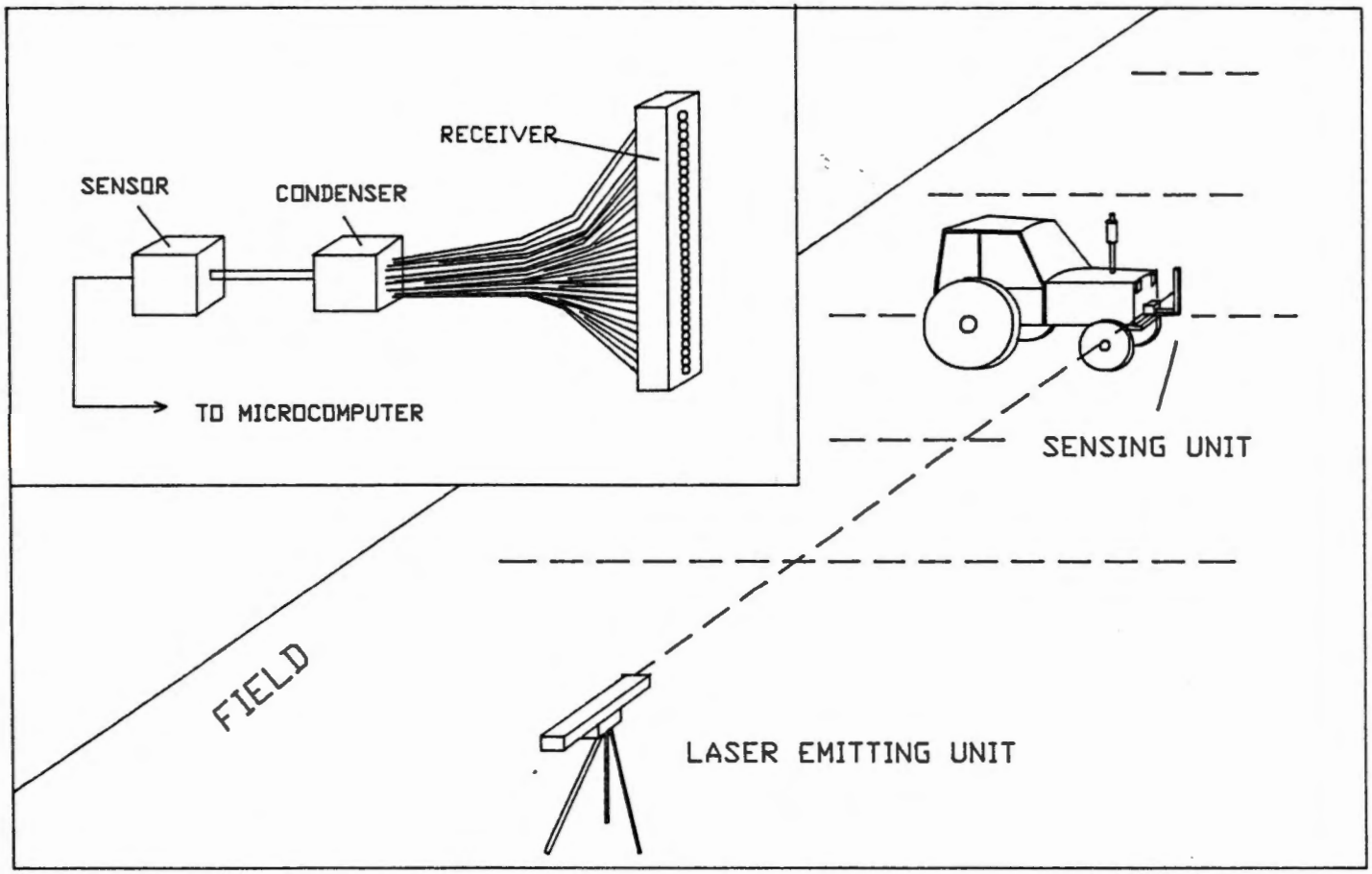


Figure 9. Array-type receiver constructed of fiber optical cable. Such a receiver might be efficiently used to detect the laser light when the receiver crosses the laser light beam.

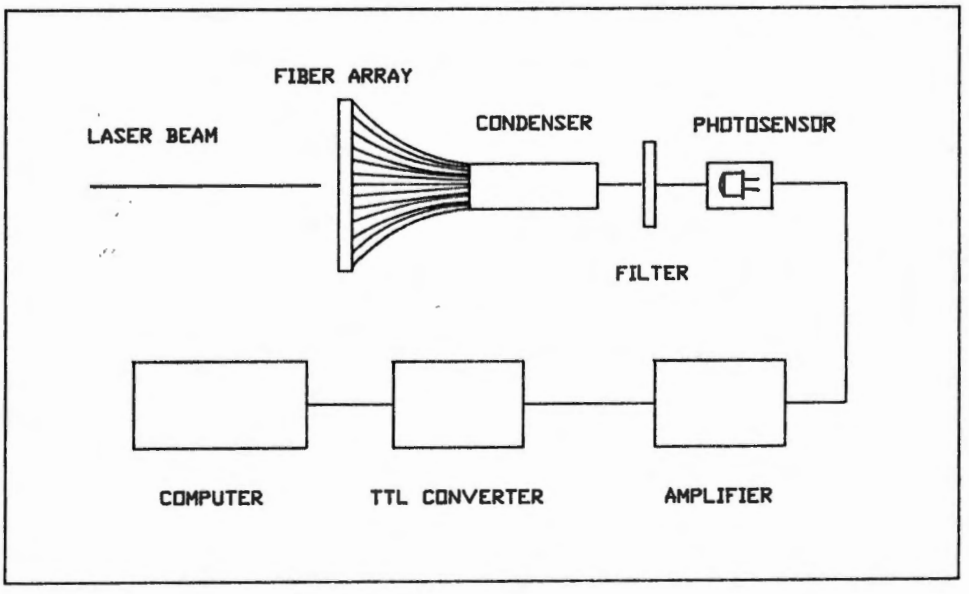


Figure 10. General layout for using a fiber optical array as part of a laser detection unit.

Plastic optical fiber which is superior to glass fiber in cost, weight, and mechanical flexibility was considered appropriate for this system. Fibers with 1 mm core diameter were selected for this project.

Several receiver circuits describing photosensing applications were available from the literature (EG&G Photon Devices, 1987). Some of these circuits included signal amplification. Since an optical filter was used in the laser receiving unit, a phototransistor or a photodarlington with high sensitivity was most desirable for use as the sensing element to detect laser light (Figure 11). Several alternative approaches utilizing a single photosensor, an optical filter, and an amplifying circuit in the detection device were considered.

(1) Use of one large-area photosensor. For the fiber array application, one end of the fiber bundle was arranged in an extended array form. At the other end, the fibers were tightly bundled in random order. Outside diameter of an individual fiber was 2 mm, and core diameter was 1 mm. If the shortest distance from the tractor to the laser emitter was arbitrarily chosen as 5 m, the laser beam diameter at the receiver would be 5 mm. If the individual fibers were arranged 4 mm apart in the receiver array, the 5-mm laser spot would cover at least one of the fiber ends as the tractor interrupted the laser beam. For a 500-mm array length, the

number of fibers = 500 mm / 4 mm = 125 strands,

total area = 125 * 3.14 / 0.9 = 436 mm^2, and

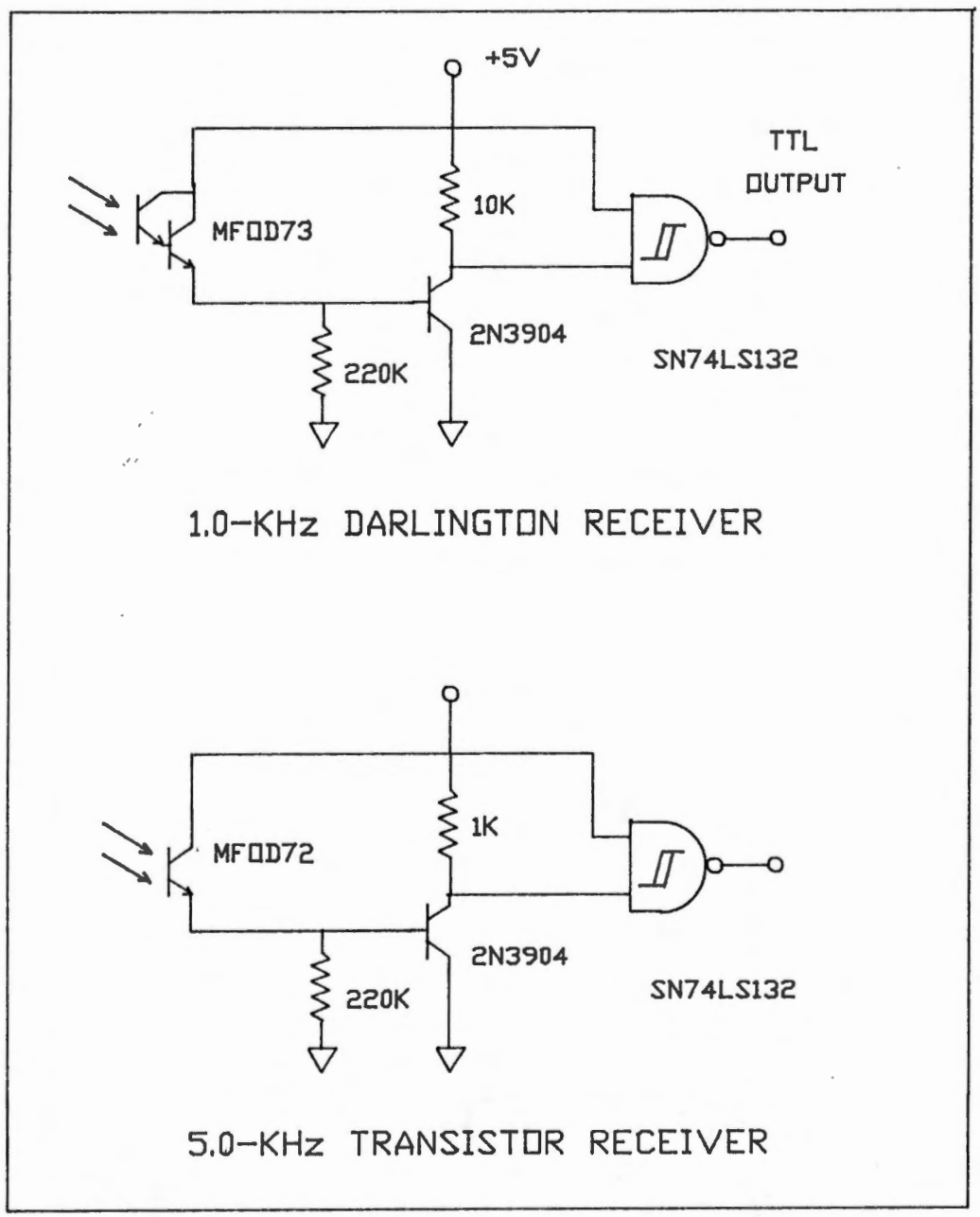


Figure 11. Examples of photosensing receiver circuits.

sensor diameter = 23.6 mm.

Since the area of the fiber bundle end was not excessively large, the entire bundle end could be placed adjacent to the window of a large-area photosensor (Figure 12). A EG&G Photon Devices DT-100 photodiode was appropriate for this application. The photodiode window diameter was 27.9 mm, which was greater than the 24 mm fiber bundle diameter.

DT-110 photodiodes are packaged in TO-36 style with a 27.9 mm window diameter. Spectral range is from 400 nm to 1150 nm. Sensitivity at 632.8 nm is 70 percent of the peak sensitivity, which occurs at 900 nm. The optical filter could be placed directly between the end surface of the bundle and the sensor window. By doing so, the amplifier circuit can be simplified because the filter eliminates most of the influence of sunlight.

(2) Use of lens to focus laser light. In this system, an optical lens could be used as a collector or concentrator to focus the light emerging from the optical fibers onto a fairly small spot. Thus, either a phototransistor or photodarlington could be used to detect the laser light (Figure 13). Koepf and Markey (1984), in their automated microposition measurement system, used a Nikkor f/1.2 58-mm focal length camera lens to collect light from fiber ends and focus it onto a silicon photodetector.

Light emerging from fibers in the bundle end adjacent to the photosensor may not be parallel. Focusing the light emerging from some fibers in the group may not be possible. But this approach could

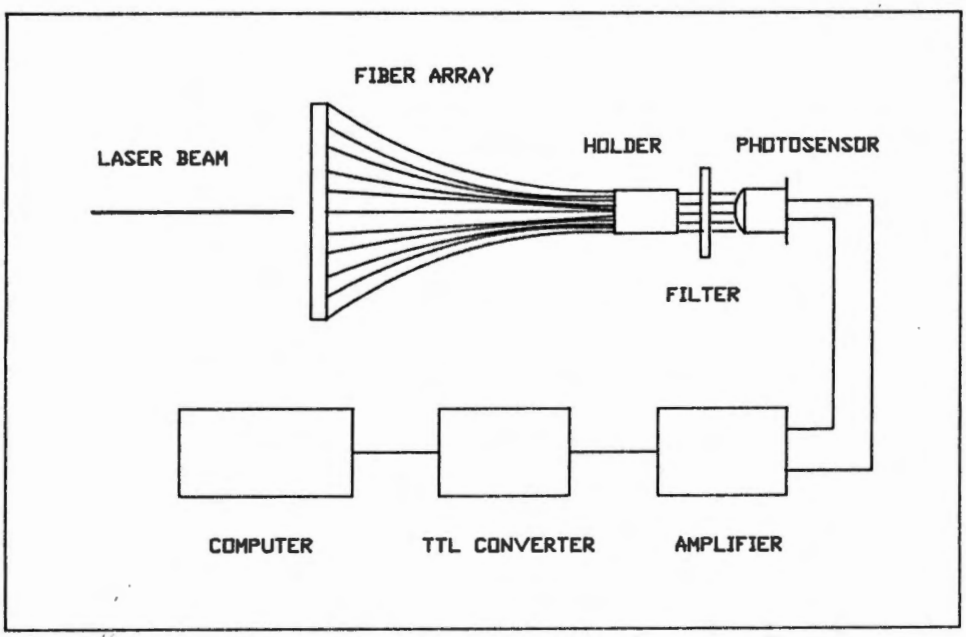


Figure 12. Use of a large sensing area photosensor in conjunction with a fiber optical array-type receiver.

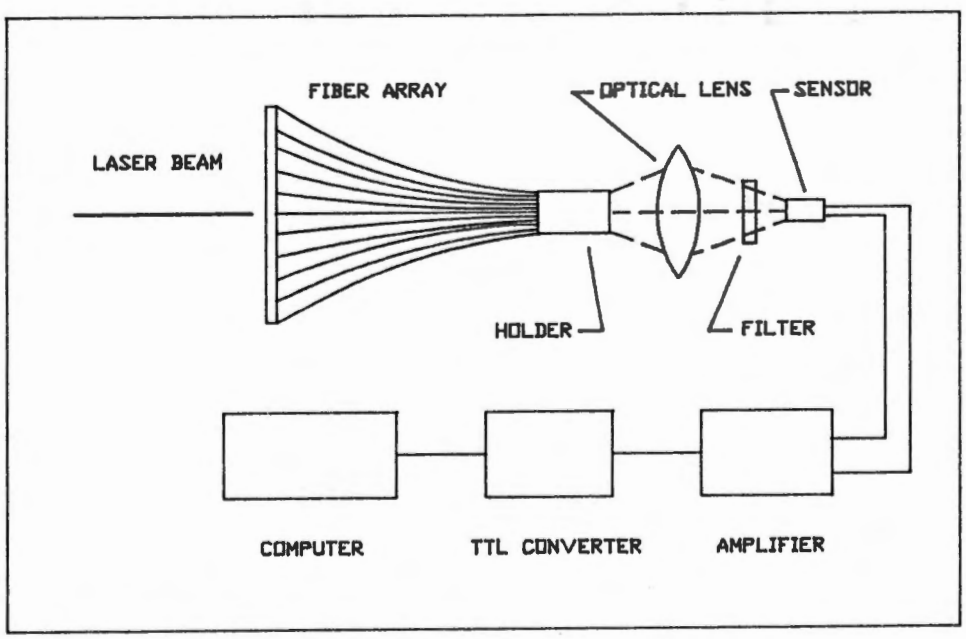


Figure 13. Application of an optical lens with an array-type receiver. The lens focuses the light allowing use of a small photosensor.

serve to considerably concentrate the light. In this case, a single photosensor which has a relatively large effective sensing area could be used to detect light emerging from the fibers.

(3) Use of fiber connectors. This concept involves using commercially-available optical connectors or couplers to merge an array of fibers into a single fiber. This single fiber then could be directed toward a single small-area photosensor.

Fiber optical couplers produced by CANSTAR can be used in passive network applications. Couplers have N (typically 4, 8, 16, 32, 64) inputs with one output. The inverse is also true. Using this device, array fibers can be combined into one output fiber. The concept is illustrated in Figure 14.

A new product called tapered optical fiber produced by C Technologies Inc. (1986) could be applied in this receiver. Tapered optical fibers have radii that vary with length. They can be used as passive optical components to alter the input and/or output connecting areas and divergence. For application in this project, the large end could be toward the fiber bundle, and the small end of the optical fiber could be directed toward the photosensor (Figure 15).

Photosensor Array with a Differential Amplifier. Two detection systems could be used together in a differential mode to alleviate problems caused from ambient sunlight (Shmulevich et al., 1987). In this system, one of the detectors is exposed to both sources of radiation, laser and sunlight. The second detector is exposed only to the sunlight and serves to measure the level of background radiation.

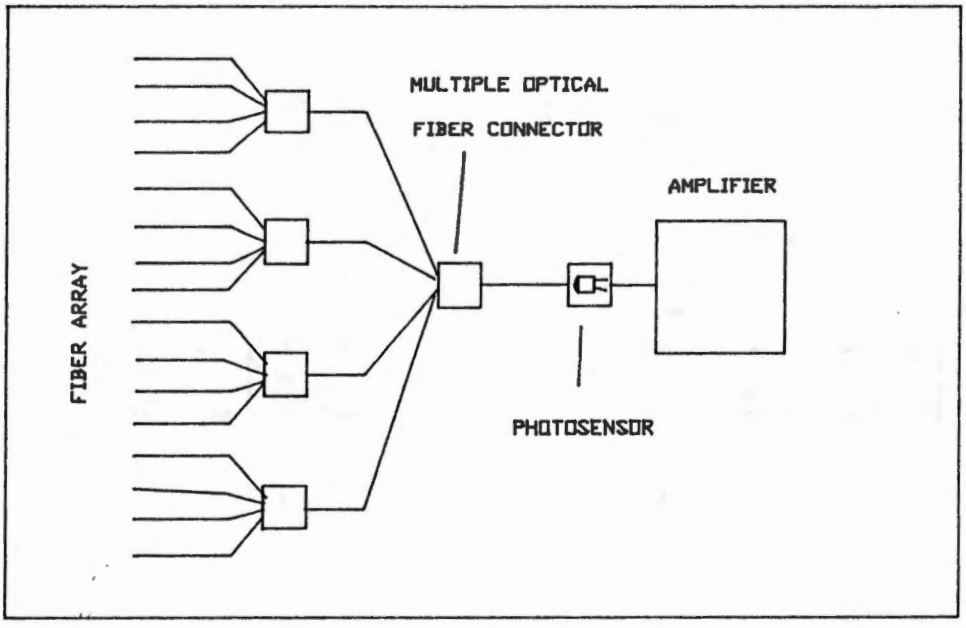


Figure 14. Concept of using fiber connectors in the construction of a fiber optical array-type receiver.

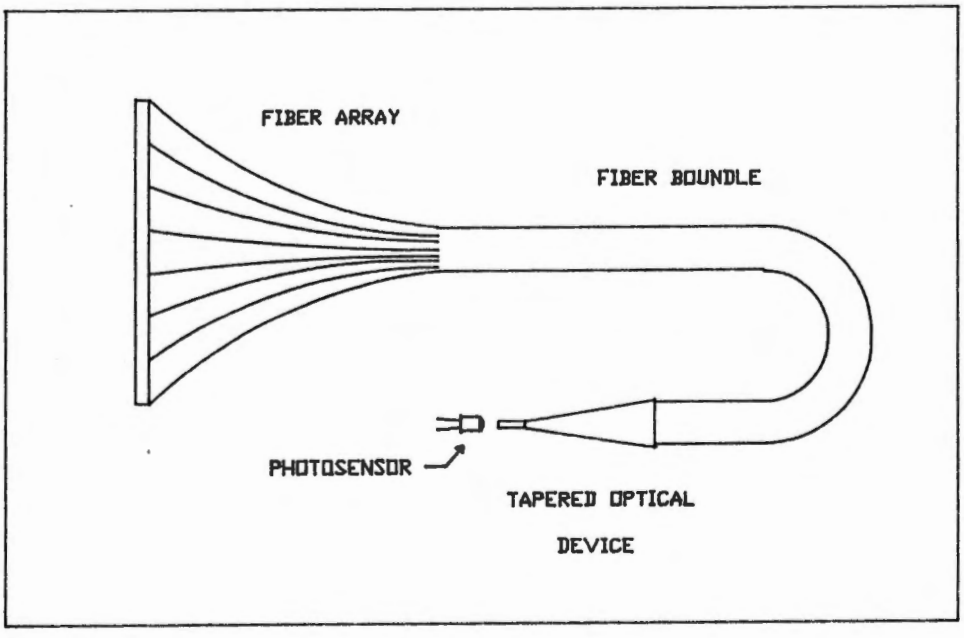


Figure 15. Concept of using tapered optical fibers in the construction of a fiber optical array-type receiver.

A differential electronic circuit denotes differences in the radiation levels, thereby detecting the presence of the laser light.

Some of the approaches discussed above require interference filters to alleviate the influence of the sunlight. Shape, size, and cost of available filters serve as design constraints. Use of optical fibers or other optical components in the receiver system requires that considerable attention be given to precision of fabrication in order to produce an accurate and reliable device.

Using photosensor arrays with a differential amplifier has many advantages. First, the receiver is a simple electronic system. The basic amplifying circuit properly configured with photosensor arrays can successfully distinguish between laser light and ambient sunlight. Such a device is low cost, easy to construct, and does not require interference filters.

The working principle of a differential amplifier is illustrated in Figure 16 (EG&G Photon Devices, 1987). Amplifier 1 (AMP1) and AMP2 are pre-amplifiers. AMP3 works in differential mode. When the two photosensors connected to the two pre-amplifiers are exposed to the same intensity levels of radiation, output voltage levels from AMP1 and AMP2 are equal. For example, when both sensors are in the dark or exposed to sunlight, output from AMP1 and AMP2 are the same. This means that the two inputs of the AMP3 are the same, resulting in no output voltage.

When the two photosensors receive different levels of radiation, AMP3 can amplify the resulting signal difference. For example, when one sensor is exposed to the sunlight while the other is

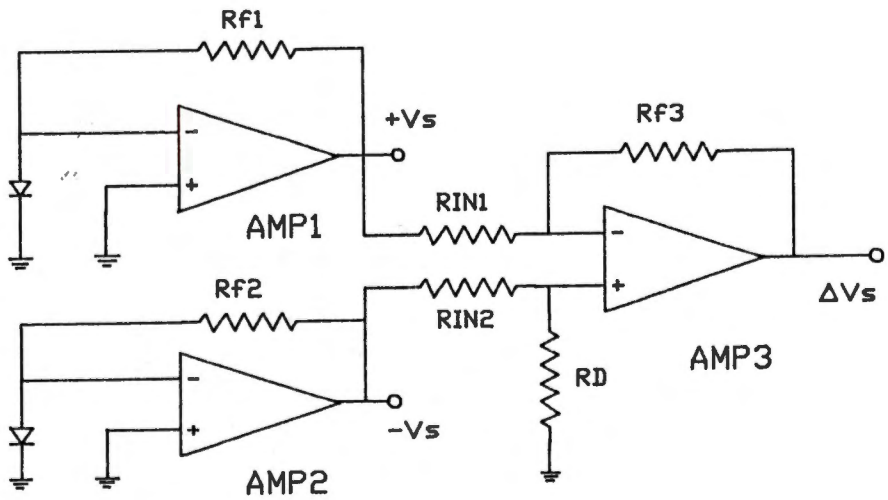


Figure 16. Basic differential amplifier circuit.

exposed to both sunlight and the laser light, then the circuit could pick up the difference and transmit a signal.

In a preliminary experiment, the differential amplifier circuit was found to be easily saturated when using either a phototransistor or a photodarlington as the sensing element. Since the level of solar radiation was high and the photosensors were both highly sensitive, output of the sensors reached its maximum value. This means that if one of the two sensors was subjected to additional light radiation, further increases in the output of the sensor were not possible. Thus, the circuit as constructed could not distinguish the laser in bright sunshine.

If the gain of AMP3 is relatively high (around 50), the circuit can be very sensitive. Even very small radiation intensity differences can cause the circuit to so indicate and generate a signal. This level of sensitivity is not desirable. Radiation reflected from trees, buildings, and even the ground may cause small radiation differences between the two photosensors. Thus, output from such a circuit may be a false signal.

A modified receiver circuit was designed (Figure 17). In this circuit, two MFOD71 photodiodes were used as sensing elements. These photodiodes have relatively high sensitivities at 632.8-nm wavelength. Like a regular differential amplifier network, this circuit included two pre-amplifiers and one central amplifier working in differential mode. A comparator was added and used as an output unit to control sensitivity of the circuit. The function of the variable resistor was to adjust the reference voltage (0.5-2.5 V) provided as input to the

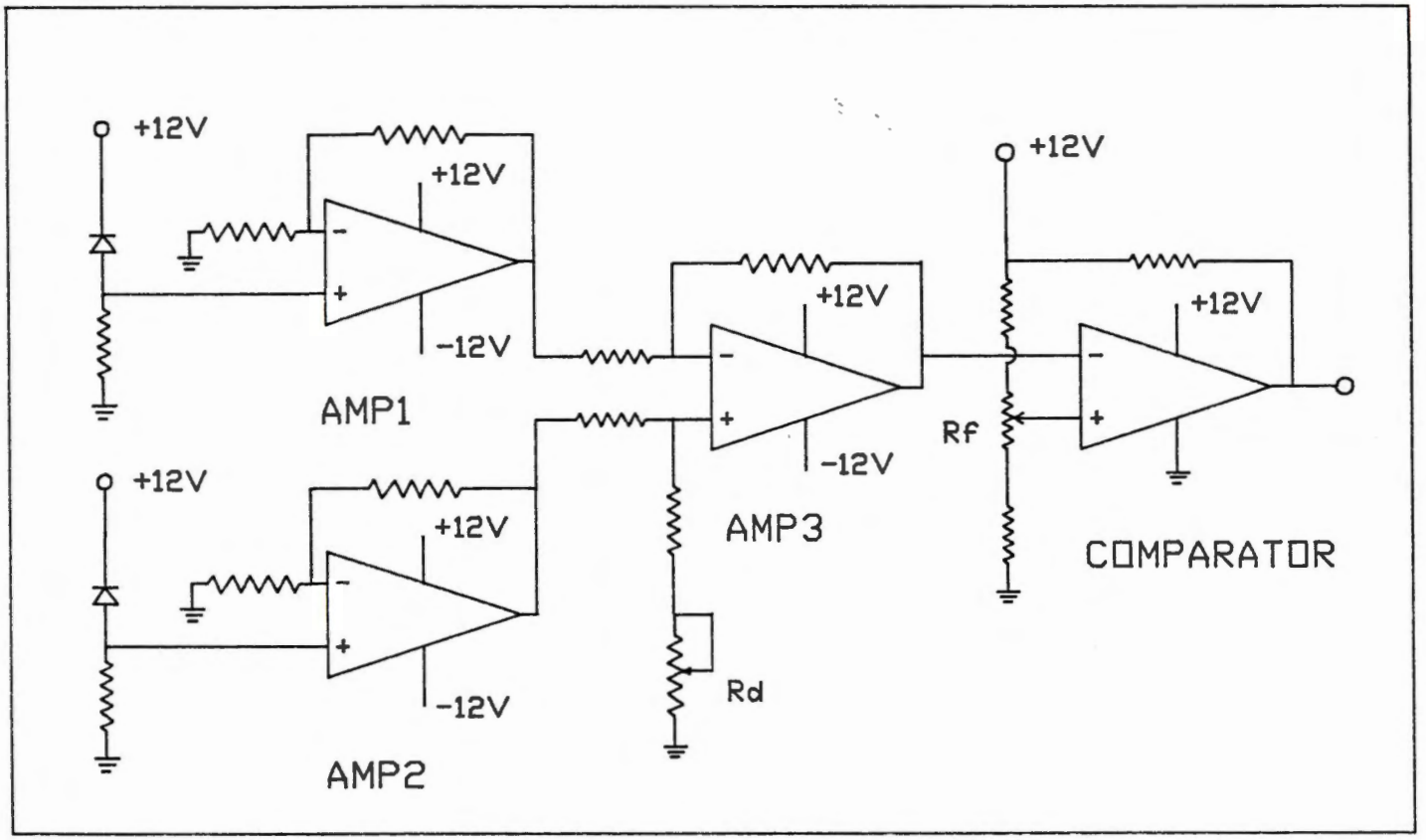


Figure 17. Modified differential receiver circuit used to distinguish laser light from sunlight.

comparator. When the output signal from AMP3 was large enough (above the reference voltage value), the comparator would amplify and send out a signal.

When such arrays and circuit are constructed, the photodiodes within each array are connected in parallel. Components must be carefully matched to balance the circuit.

IV. LASER BEAM ENERGY DENSITY TEST

Tests were conducted to ascertain the sensitivity of the laser detection device and to determine the relationship between sensitivity of the photosensors and operating distance. A simple circuit was constructed as shown in Figure 18. A MFOD71 photodiode was used as a sensing element in the circuit. Test distance was increased in 3-m increments. For each test distance, output voltage of the circuit was recorded. During tests at each distance, the power supply was operated at both 5 and 12 volts. The purpose of using these two power supply systems was to determine if performance was affected by power supply voltage.

Results of this test showed that response of a single sensing element such as a photodiode was not linear with distance from laser emitter to sensor (Figure 19). Energy density of the laser beam dramatically decreased as distance increased. Compared to low voltage, the high voltage power supply value actually did not make much difference when the distance between emitter and receiver was greater than 15 m.

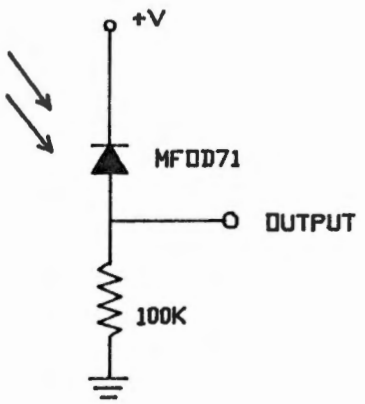


Figure 18. Simple receiver circuit used for laser beam energy density test.

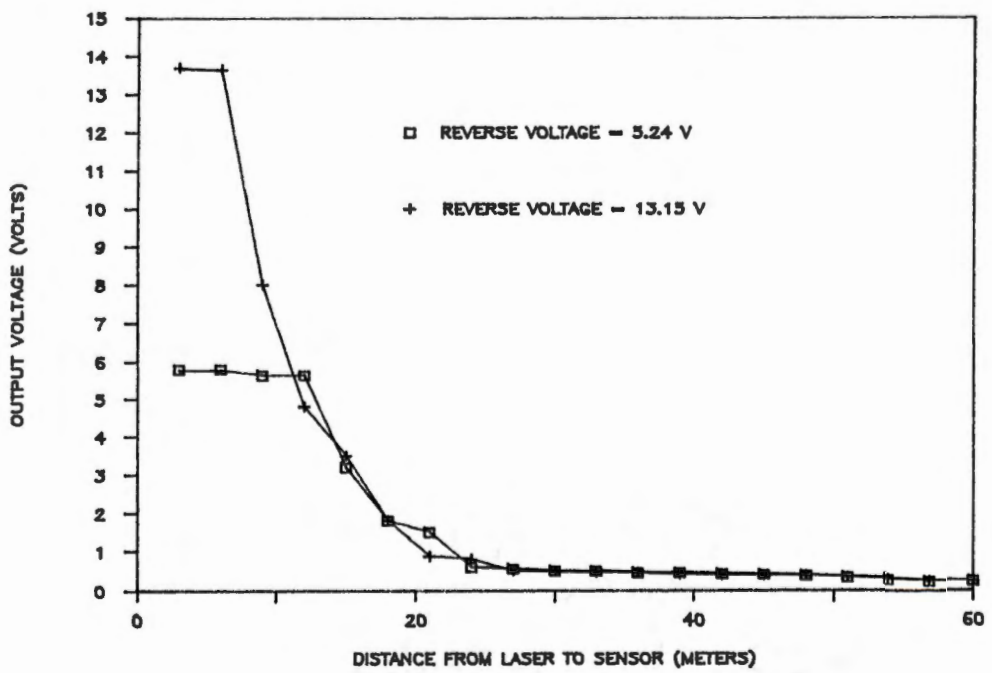


Figure 19. Results of the laser beam energy density test showing photosensor response as a function of test distance.

V. TEST OF SYSTEM WORKING RANGE

Simple Laser Receiver

Before addressing the problem caused by the intense sunlight on the receiver, a test was conducted at dusk to determine the working distance capability of the emitter-receiver system when bright sunlight was not present. This experiment revealed that the basic sensing element with only one degree of signal amplification through a regular transistor could detect the laser light when the receiver was at least 120 m from the emitter. As test distance was increased beyond this range, the basic sensing unit could not detect the laser beam since the light density of the beam was substantially reduced due to divergence. In addition, attenuation of the laser beam in the course of its travel through the atmosphere probably resulted in less power density. However, adding more than one degree of signal amplification would enable the sensing unit to successfully detect the laser light at a greater distance.

Fiber Array Applications

A simple receiver consisting of a single optical fiber, an optical filter, a phototransistor, and a receiver circuit was constructed. The optical fiber was used as a waveguide. One end of the fiber was directed toward the laser light source, and the other end faced toward the photosensor. The optical filter was placed between the fiber and the photosensor to minimize the influence of sunlight. The receiver was equipped with a light-emitting diode (LED)

to indicate if the receiver was sensing the laser light. The apparatus was set up outdoors to test the working range.

Use of the plastic optical fiber and the optical filter reduced the sensitivity of this receiver. Maximum working range did not exceed 40 m. When the phototransistor was replaced by a photodarlington and the circuit was altered to accommodate the change in sensing element, the receiver could detect the laser light when the emitter was placed more than 100 m away.

Test results showed that the working range was limited because the sensing area was small (1-mm diameter) and the energy density of the laser beam was reduced dramatically as distance from the emitter was increased. However, if a fiber array was used in this application, working range of this receiver would likely be much improved. Several fibers (more than one) within the array would receive light from the laser. Since diameter of the laser beam increases with distance, more fibers would receive light as the distance increased. Fiber ends still must not directly face the sun; otherwise, the receiver circuit would generate a signal continuously. Solar radiation with wavelengths near 632.8 nm entered the optical fiber and was detected by the photosensor.

Photosensor Array with a Differential Amplifier

Use of a differential amplifier has some advantages over the fiber array approach. Experimental results showed that the basic sensing system was working quite well. In initial tests, two MFOD71 photodiodes were used as the sensing elements. Three 741 integrated

circuits were used in the receiver circuit as amplifiers. One 339 integrated circuit was used as a comparator to control the sensitivity of the circuit and to amplify the output signal.

An experiment with this receiver was carried out to test its working range outdoors under the sunlight. Output voltage levels from both AMP3 and the comparator were recorded when the receiver was moved away from the laser emitter in 3-m increments. Experimental data showed that working range increased to a maximum of 72 m (Figure 20). Limitation in working range was attributed mainly to the small sensing area of the single photodiode and the decreased energy density of the laser beam as the distance from the laser emitter increased.

After the MFOD71 photodiodes were replaced with the MRD500 photodiodes, which have a larger sensing area, working range was increased. In an additional experiment, two MRD500 photodiodes were arranged in each array. Functional test distance increased to over 110 m. During the experiment, the circuit had to be placed under shade to avoid overheating. When left uncovered in direct sunlight, the system malfunctioned.

A working range test using a differential amplifier receiver with more than five photodiodes arranged in each array was not conducted outdoors because the circuit did not function in this environment. Even in the laboratory, the circuit could not detect the radiation difference between two arrays when a single photodiode in one of arrays was exposed to the laser beam.

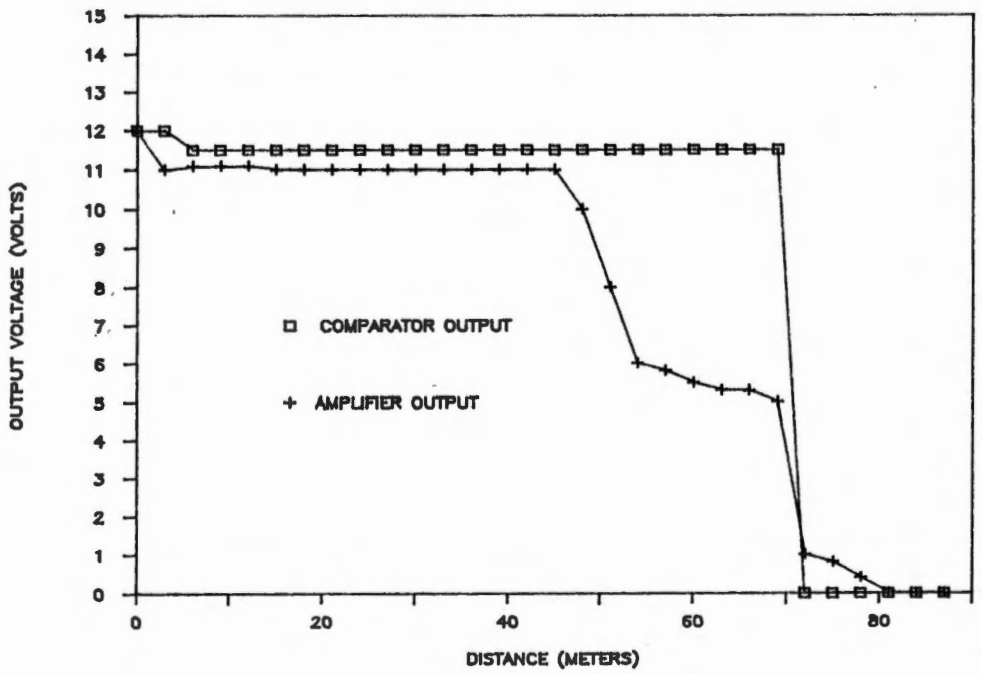


Figure 20. Results of the working range test using the laser receiver with a differential amplifier. MFOD71 photodiodes were used as sensing elements in the circuit.

VI. DISCUSSION OF RESULTS

Finding an acceptable device to collect laser light from the array-type receiver and send it to a single photodetector was considered important. After analyzing several different methods for receiving and detecting laser light, no system emerged as clearly superior. Furthermore, very few similar applications were available for reference.

Many of the methods mentioned earlier for collecting laser light from the fiber array were not tested due to the prohibitive expense associated with obtaining necessary components. The method employing a lens to focus the laser light from multiple fiber ends onto a small point was examined. Results were not encouraging due to the divergence rate of laser light emitted from the fibers and to the rough surface condition on the fiber ends. This system required very precise construction and orientation of the optical components. The fibers, the lens, and the sensor must be kept in precise alignment.

For actual field application of a photosensor array equipped with a differential amplifier, the array receiver should be long enough to accommodate substantial elevation changes with the vehicle. In a further experiment, ten MRD500 photodiodes were arranged in each array and connected in parallel within the circuit. In outdoor conditions, each photodiode has a certain level of current flow due to the solar radiation. Total current flow through the resistor from which the pre-amplifier picks up the signal will be relatively large. When one of the photodiodes in the array is excited by additional

light from the laser beam, the current change on that resistor will be very small because the excited element is only one of several photodiodes used in the array. In this instance, output voltage from both arrays can remain very close to the same level. When this occurs, there is no output from AMP3 because the magnitudes of the two input signals differ very little.

If the gain of AMP3 is increased, the circuit can amplify this small difference and obtain a discernable output signal. However, the circuit becomes very sensitive to the input signals as the gain of AMP3 is increased from 20 to 100. Naturally-occurring small difference in radiation levels can cause the circuit to send out a signal, falsely indicating laser beam detection.

In summary, using photodiode arrays presented problems. The array decreased the input signal difference for the two pre-amplifiers. When the circuit was used outdoors, this made the circuit fail to function due to the strong solar radiation levels. If the circuit was adjusted by increasing current gain to allow sensing of small radiation differences, variations in radiation level occurring in the operating environment could cause the circuit to send a false signal. Therefore, use of several photodiodes arranged in an array is not a suitable approach for this application.

Results of preliminary experiments revealed that building an inexpensive yet effective receiving array presented a potential challenge. In using a fiber optical array, a lens was not effectively employed to focus the laser light from fiber bundle onto the photosensor. Expense of optical couplers and tapered optical fibers

prohibited even testing of the concept using connectors to fabricate the receiving network. Several photodiodes were united to produce a larger sensing area. This set of photodiodes was placed behind the fiber bundle. Results of laboratory experiments using the apparatus showed that the gaps between adjacent photodiodes would result in missing light emitted from some fibers.

Application of a differential amplifier was helpful in reducing the influence of sunlight. However, the number of photodiodes that could be used in each array was limited. If a long array receiver was built, more electronic circuits would be required to achieve this goal.

Many problems remain to be solved before the laser receiver can effectively be mounted on the tractor. Since the receiver is moving with the tractor, the factors which hampered operation of the several laser detection devices used in the field and laboratory tests will be accentuated.

CHAPTER IV

DEVELOPMENT OF THE FINAL PROTOTYPE TRIGGERING SYSTEM

I. FINAL PROTOTYPE TRIGGERING SYSTEM DESIGN

Triggering System Description

Since the previous laser-based triggering system prototypes were not fully successful, a new approach was taken in developing the final system prototype. The final design concept involved arranging the lasers to form parallel lines as in the previous approaches. However, receivers would be placed opposite the laser emitters and continually sense the laser light. When the tractor interrupted the laser beam, the receiver would detect the absence of the laser light and generate a signal (Figure 21). Since both laser emitter and receiver are stationary on the ground, a simplified receiver can be used to sense the laser light. A shade and an optical filter could be used to mitigate the strong influence of sunlight on the receiver. Only a single photosensor is required since alignment is not constantly subject to change. However, since the receiver would not now be mounted on the tractor, a remote signal transmission and receiving system allowing communication between the stationary laser detector and the moving tractor would be required. While the laser detection process has been simplified in this approach, the communication system has become substantially more complicated and sophisticated.

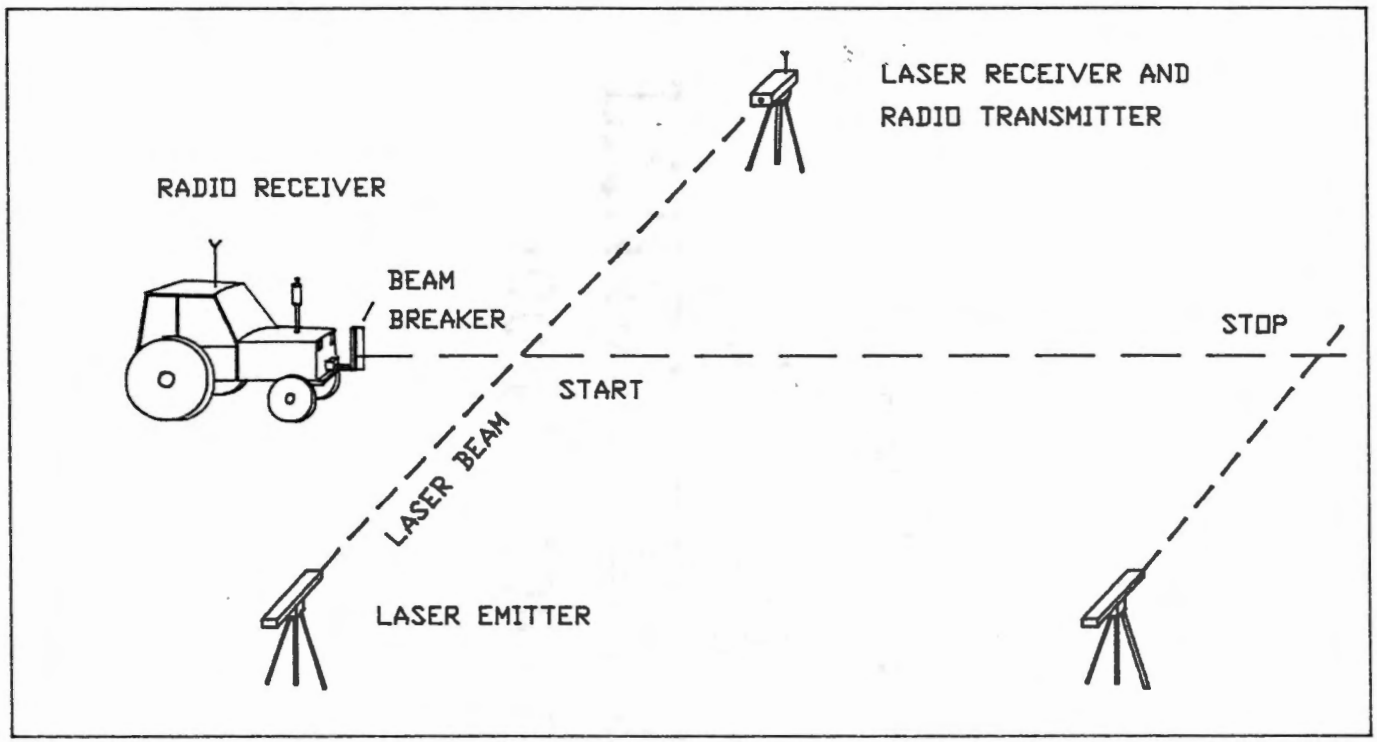


Figure 21. Operating principle of a laser triggering system in which the laser receiver is located in a stationary position on the ground opposite the laser emitter.

The principal advantage of the approach described above is that the laser receiver does not require an array-type sensing element. Thus, design of the laser receiver is greatly simplified. Additionally, more accurate performance of the system is likely to be achieved, especially during operation over extended distance, because of greater receiver stability.

Divergence of the laser beam will not affect the precision of the measurement. Only when the tractor reaches the line connecting the laser emitter and the active photosensor receiving surface will the laser beam be effectively interrupted. Thus, the receiving unit can be placed as far away from the emitter as it has capacity to sense the laser light, and precision of the measurement will not be affected.

The method described in the previous chapter can be used for placing and aligning the laser emitting units. The opening to the photosensor in the receiver housing should then be placed in the center of the beam at an appropriate distance down range from the emitter.

The Laser Receiver

Since the receiver is stationary and positioned to receive the center part of the beam, a fairly long narrow shade can be used to cover the housing to reduce direct exposure to sunlight. The final laser detecting circuit was equipped with a MRD500 photodiode as a sensing element. This photodiode has a convex focusing lens. A 324 operation amplifier was used to amplify the signal from the

photodiode. To reduce the zero offset of the circuit, a transistor was used as a pre-amplifier before the 324 operation amplifier. A comparator controlled the circuit sensitivity and provided a constant output voltage. A low-current relay was used as an output device. The circuit is shown schematically in Figure 22.

The circuit was designed to generate a signal when the laser radiation on the photodiode was blocked or when the photodiode was in the dark condition. No output signal was produced when the photodiode was exposed to the laser beam. Since the laser receiver was exposed to the laser light most of the time during field operation, the 9-volt battery powering the circuit was expected to be effective for a considerable period.

To allow the circuit to have a reasonable working range for a variety of different background light conditions, the reference voltage provided to the comparator was made adjustable. When the background light is less intense, this reference voltage can be adjusted downward to increase the circuit sensitivity. On a very bright, sunny day, the voltage can be increased to allow the circuit to still respond and maintain a reasonable working distance. An external potentiometer (100KΩ) was used in the circuit. Reference voltage could be adjusted from 1 to 5 volts.

Radio Communication System

A radio communications device was selected to transmit signals from the stationary laser receiver to the microcomputer mounted on-board the moving tractor. Radio transmitter and receiver subsystems

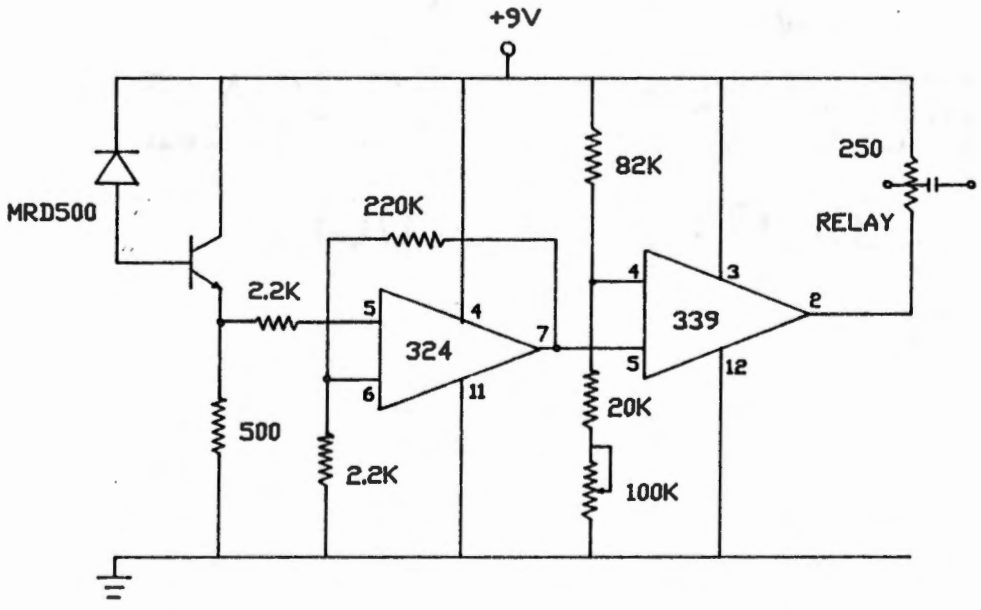


Figure 22. Laser receiver circuit in the final triggering system design.

are commercially available. The radio transmitter, which consists primarily of two components (a frequency generator and a signal transmitter), sends a constant frequency radio wave.

To avoid interference by other nearby extraneous radio signals, the receiver should pick up a narrow band of signals characterizing the transmitter frequency. This requirement was accomplished by using a frequency encoder in the radio receiver.

An inexpensive radio transmitter and receiver set with a reasonable working range could be effectively used with the laser detection system. A remote control set complete with two transmitters and one receiver commonly used to remotely actuate residential garage doors was selected. The units were produced by PULSAR Control Corporation. Normal working range is less than 45 m. The radio transmitter is powered by a 9-volt battery, while the radio receiver required 12 volts DC, which could be supplied by the tractor battery.

The laser receiver circuit was configured to control operation of the radio transmitter through a normally-open relay. When a beam breaker installed in the front of the tractor interrupts the laser beam during field operation, the laser receiver closes this relay and allow the radio transmitter to send out a pulse signal.

Components of the laser receiver and the radio transmitter were assembled in a protective plastic box, as is shown schematically in Figure 23. The box itself served as a shade to provide a darkened space for the photosensor. A small opening in the front of the box allowed laser light to enter and excite the photodiode in the receiver circuit. A LED mounted on the side of the box gave a visual

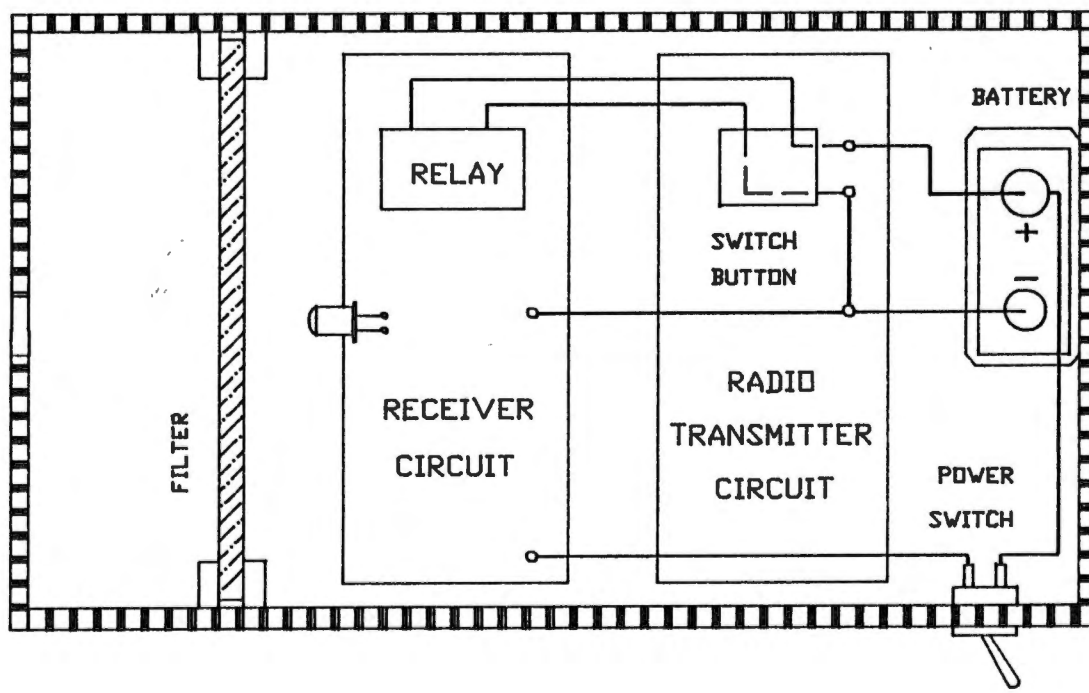


Figure 23. Schematic of the final receiver prototype including the laser receiver and the radio transmitter.

indication of the working status of the radio transmitter. This LED proved very helpful in adjusting the sensitivity of the circuit to match the light conditions and distance between emitter and receiver.

A radio receiver installed on the vehicle received the pulse signal generated by the transmitter at the laser receiver and triggered another relay to send a signal to the computer controlling data acquisition. System construction is summarized in the block diagram shown in Figure 24. A TTL signal is required for initiating and terminating data acquisition through the tractor-mounted computer. Since the output signal of the radio receiver is conducted through a relay, its form is that of a TTL signal. Thus, relay output can be directly interfaced to the computer.

Interfacing Unit and Software

The function of the interfacing unit was to connect the signal generated by the radio receiving unit to the microcomputer which controlled operation of the data acquisition system. To initiate and terminate the data acquisition process in the correct sequence during actual field operation, a simple computer program was developed to handle the TTL signals coming from the radio receiver. Since the tractor was moving back and forth across the experimental plot in multiple test runs, every "on" or "start" signal would be followed by an "off" or "stop" signal, or vice versa. In other words, alternate signals generated at the laser receiver carried the same function. Primary construction of this software program is outlined as follows:

10 a "start" signal is received

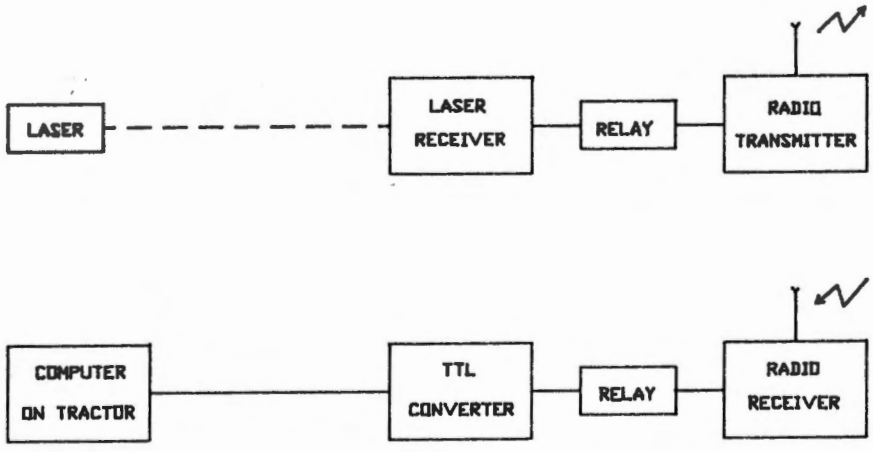


Figure 24. Block diagram showing the operating principle of the final remote triggering system prototype.

```
20   start the data acquisition process
30   upon receiving a subsequent signal, stop data acquisition
40   upon receiving the next signal, go to 20
```

II. FINAL PROTOTYPE SYSTEM TEST

Test of System Working Range

When the final triggering system prototype equipped with a radio communications device was completed, the unit seemed to work very well outdoors. Since a long narrow shade was used, influence of sunlight appeared to be dramatically reduced. Three levels of amplification were available in the receiver circuit. Thus, the laser receiver could detect the laser light over an extend working range.

Outdoor test results showed that, in a dark environment, the receiver could sense laser light at a distance of over 150 m when the potentiometer was adjusted to the position allowing greatest sensitivity. In the sunny environment, the receiver could sense laser light up to 90 m when the potentiometer was adjusted to an optimum position compatible with the light conditions.

System Repeatability Test

A series of tests were conducted in the laboratory to determine the accuracy of this triggering system. A personal computer was used to measure time and record data. Receiver-to-computer interfacing was accomplished by using an IBM E. D. P. EQUIP. 167G interface unit. In this test, a pulse generator provided a constant clock frequency for the computer. The computer counted and recorded

the number of digital pulses through the counter-board in a certain time interval. Starting and stopping of the counter were controlled by the laser triggering system through a BIN post on the A/D board.

Two methods, described below, were used to break the laser beam at constant time intervals. When the laser beam was interrupted such that light did not reach the laser receiver, the receiver unit would generate and send a signal. The radio receiver then detected this signal and triggered the counter to start. When the next similar signal was received, the counter was stopped. The computer recorded the number of clock pulses occurring during this interval between start and stop.

Low-Speed Motor. A low-speed motor with an impeller was used to break the laser beam at a constant time interval. Angular velocity of the motor was 10 rpm. Thus, the beam was interrupted once every 6 seconds.

A BASIC computer program was written to count and record the number of pulses between two beam interruptions (See Appendix A). Raw data were saved on a floppy disk for subsequent analysis. Based upon the frequency produced by the pulse generator and the number of pulses recorded by the computer, the time duration for each event could be calculated using the following expression:

Time = Number of Pulses / Frequency.

Clock frequency was set at 147.38 Hz for the first data set. From the recorded data, average time duration was 6.0006 seconds, and standard deviation of the data was 0.0060 second. The system had very

good repeatability as indicated by the data shown in appendix A. For the second test, the clock frequency was increased to 1120.9 Hz. Measured average time duration was 6.0022 seconds, and standard deviation was 0.0059 second (See Appendix A). The test data indicated that the clock frequency had little effect on the measurement accuracy.

Pendulum Device. A pendulum test device was used to break the laser beam, providing a very precise, constant time interval between beam interruptions. Length of the pendulum was 5.02 m. Mass of the ball was 15.42 kg, and diameter of the ball was 152.4 mm. The pendulum was suspended from the ceiling of a laboratory. A beam breaker was attached to the 1.2-mm diameter steel spring music wire of the pendulum mass at the elevation of the laser beam.

To establish an ideal test environment for the pendulum, doors were closed and air-handling systems were turned off. To avoid vibration and hysteresis in the path of sway, the pendulum was started by placing a loop of cotton string around the ball. The ball was displaced 500 mm from the plumb line by pulling the string. After the ball was stabilized, the cotton string was burned, releasing the pendulum. This allowed the pendulum to oscillate smoothly, free of vibration and hysteresis.

A BASIC computer program was written to measure the period of the pendulum (See Appendix B). The pendulum device interrupted the laser beam twice for each cycle of oscillation. The computer counted the number of pulses for each cycle by starting the counter at the

pulse signifying the first interruption and by stopping the counter at the third pulse signal. To increase execution speed of the computer program so as to reduce measurement error associated with the program itself, the BASIC program was compiled. A high clock frequency (around 100 kHz) was provided to the computer.

Tests were conducted, and both laser receivers were used for comparison. More than 78 data points were collected for each test. Results were satisfactory. Average measured cycle time was 4.1758 seconds for one of the receivers, and the standard deviation of the data was 0.0017 second. The average value was 4.1761 seconds for the second receiver, and the standard deviation was 0.0017 second (See Appendix B).

III. DISCUSSION OF RESULTS

Results of system working range tests showed that the receiver could detect laser light up to 90 m away under the sunlight. At this distance, however, the range of stable operation of the radio transmitter and radio receiver was exceeded. Even if the radio receiver had been replaced with a different model equipped with a standard antenna, the working range of the communications system was still less than 40 m.

Results of system repeatability tests using the pendulum indicated that the final laser triggering system prototype is quite satisfactory. Results indicate that the system has very good measurement repeatability. The event interval can be accurately measured to at least one hundredth of a second. During the tests, the

clock frequency indicated by the frequency counter varied somewhat. In fact, the frequency variation reached 30 Hz for one test. Since the measurement system based on a personal computer itself could not work very precisely for such a time measurement, and a very constant clock frequency was not maintained, subsequent errors were included in the test results. If a more accurate measurement system had been used for tests, and a constant clock frequency was maintained, measurement may have been more accurate.

Release time of the relay in the radio receiver was measured to be 0.68 second (See Appendix A). If the time interval to be measured is less than this value, the system can not respond fast enough to catch the second signal. However, this will not present a problem in field operation because the test course is typically 60 m in length and requires several seconds to traverse.

Tests also showed that if the beam breaker blocked the laser beam for a very short interval (about 0.045 s), the radio receiver on the tractor will not respond even though the transmitter in the laser receiver functions. This observation suggests that the laser beam breaker be broad enough (100 mm wide for 8-km/h tractor operating speed) to allow enough time for the radio set to respond.

IV. TRIGGERING SYSTEM EVALUATION

A radio communications device was applied in the final triggering system prototype. Although this approach added hardware, and

complicated system design, many potential problems associated with using an array receiver were eliminated.

Primary problems with using the vehicle-mounted array-type receiver were associated with alignment and beam detection under bright sunlight. These problems were easily solved by using a stationary receiver and a signal communications system. The triggering system prototype worked very well. Any errors caused by final triggering system were shown to be very small and, for most practical purposes, negligible. However, for field operation, one additional parameter must be considered. The laser beam must be interrupted only once when the vehicle passes through. Computer software could be used to solve this problem rather easily by accepting only the first pulse from the radio receiver. Subsequent pulses delivered within some prescribed time interval after the first pulse will be neglected.

CHAPTER V

SUMMARY AND CONCLUSIONS

I. SUMMARY

To initiate and terminate data acquisition using an instrumentation package mounted on a test tractor, a remote automatic triggering system that would allow actuation precisely at designated locations in the field was sought. Several possible triggering system alternatives were analyzed and evaluated. These included: (1) a contacting wire, (2) a radar or an ultrasonic sensor, (3) a laser-based triggering device. Finally, a laser triggering system was selected to accomplish the system design.

The triggering device consists of three subsystems: (1) a laser emitting unit, (2) a laser receiving unit, and (3) a interfacing unit. Two 5-mW helium-neon lasers are used to provide precise reference lines which represent the end points of the field plot. A photodiode in the laser receiver is used to detect laser light. Signals from the laser receiver are interfaced to a microcomputer mounted on the tractor to precisely control the data acquisition process.

Two prototypes of the laser-based triggering system were investigated. In the first design, the laser emitting unit is set at the side of the field. When the instrumented tractor passes the laser beam which defines the starting or stopping line, the laser receiver mounted on the front of the moving tractor will sense the laser light

and send a pulse signal to the microcomputer to precisely initiate and terminate the data acquisition process.

In the final triggering system design, the laser receiver is located in a stationary position at the side of the field opposite the laser emitter. Laser light is continuously detected at the laser receiving unit. A radio remote control device is used to achieve signal communication between the laser receiver and the microcomputer on the tractor. When the instrumented tractor passes through the laser beam, interruption of the beam causes the laser receiver to actuate a radio transmitter included in the receiving unit. Signals generated by the radio transmitter excite a radio receiver mounted on the moving tractor. The radio receiver then signals for initiation or termination of the data acquisition process.

In the final laser receiving unit design, an optical filter was used to alleviate the influence of sunlight. A single MRD500 photodiode sensed the laser light, and a receiver circuit was designed to accommodate changes in light conditions and working range. A commercially-available radio remote control set was directly applied in the final triggering system to accomplish signal communications between the laser receiver and the microcomputer mounted on-board the moving tractor.

II. CONCLUSIONS

Observations and test data acquired during the development of a prototype laser-based triggering system for remote actuation of

tractor-mounted data acquisition instrumentation resulted in following conclusions:

1. Design requirements for a tractor-mounted array-type receiver were difficult to satisfy. Primary problem areas included insuring that the receiver was always at the elevation of the laser beam and distinguished between sunlight and laser light under variable environmental conditions.
2. Placing the laser receiving unit in a stationary position to constantly detect the laser beam simplified receiver design markedly. Only a single photosensor was required for a given receiver. This photosensor could be shaded in a housing to protect from direct exposure to sunlight. An optical filter which passed light with wavelengths near 632.8 nm, the laser light characteristic wavelength, further reduced the influence of sunlight.
3. The laser receiver equipped with a single MRD500 photodiode could detect the light emitted by a 5-mW helium-neon laser at a distance of 150 m in indoor tests. When tested outside in bright sunlight, the maximum distance that the laser light could be detected was reduced to 90 m. The sensitivity of the detection system was adjustable through a potentiometer.
4. Mounting the laser emitting units on the telescope portion of a standard builder's transit-level simplified the

process of aligning the lasers in the field. The laser emitting units could be placed the desired distance apart and the laser beams aimed directly toward each other. If the two instruments were then rotated 90 degrees in the horizontal plane as indicated by the reading on the horizontal circle of the surveying instrument, the laser beams would be parallel to define the ends of a test track.

5. A radio transmitter at the laser receiver was effective in exciting a radio receiver mounted on the tractor when the laser beam was interrupted. The radio receiver on the tractor subsequently signaled for actuation of the data acquisition instrumentation. The radio communications equipment was the limiting factor in determining the working range of the triggering system. The radio system did not reliably function at distances greater than 40 m.
6. The system was able to repeatedly time events with a precision of 0.01 second.

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APPENDIXES

APPENDIX A

DATA COLLECTION PROGRAM AND DATA FROM TESTS USING LOW-SPEED MOTOR TO BREAK BEAM

```
10  '*****************************************************************
20  '*        This program designed by Tom E. Droz was used for      *
30  '*  measuring the time duration between two signals from the     *
40  '*  laser receiver.  A low-speed motor with an impeller was used *
50  '*  to break the laser beam.  A TTL signal coming from the relay *
60  '*  of the radio receiver was interfaced to the computer to      *
70  '*  provide a binary input to control starting and stopping of   *
75  '*  the counter.                                                 *
80  '*****************************************************************
85
90  REM initialize variables
100 ADAPT%=0:ID%=8:OD%=8:CD%=10:CHLO%=0:SETUP%=0:STAT%=0
110 PS%=&HFFFF:LAS%=15
120 GOTO 200
125
130 REM subroutines let the program wait for transitions from A/D
140 REM board
150 CALL BITINS (ADAPT%,ID%,LAS%,LAST%,STAT%)
160 CALL BITINS (ADAPT%,ID%,LAS%,FLAG%,STAT%)
170 WHILE LAST%=FLAG%:CALL BITINS (ADAPT%,ID%,LAST%,FLAG%,STAT%):WEND
180 RETURN
190
200 REM main program which counts the number of pulses
210 REM and outputs the result in form of seconds and
220 REM writes the pulse number in output file
230 GOSUB 1000
235 WHILE INKEY$=" "
240 GOSUB 150:CALL CSET (ADAPT%,CD%,CHLO%,SETUP%,PS%,STAT%)
250 PRINT "time reset  ";STAT%
260 GOSUB 150:CALL CINS (ADAPT%,CD%,CHLO%,SECOND%,STAT%)
270 PRINT "second xition ";-SECOND%*SCALE
280 GOSUB 150:CALL CINS (ADAPT%,CD%,CHLO%,FINAL%,STAT%)
390 PRINT "final count  ";-FINAL%*SCALE
300 GOSUB 150:CALL CINS (ADAPT%,CD%,CHLO%,LAST%,STAT%)
310 PRINT#1,-SECOND%,-FINAL%
320 WEND
330 CLOSE:END
340
1000 REM subroutine for opening an output file
1010 INPUT "enter clock frequency in Hz";Hz:scale=1/Hz
1020 INPUT "enter file name";F$
1030 IF F$="" THEN STOP
1040 IF INSTR(1,F$,".")=0 THEN F$=F$+".PRN"
1050 OPEN F$ FOR OUTPUT AS #1
1060 RETURN
```

DATA WERE TAKEN FOR MEASURING THE REPEATABILITY OF THE
DATA WERE TAKEN FOR MEASURING THE REPEATABILITY OF THE
TRIGGERING SYSTEM
DATE : JUNE 29, 1988
CONDITION: CLOCK FREQUENCY = 147.38 Hz
EQUIPMENT: 3010 FUN. GEN., LOW-SPEED MOTOR (10 RPM)
FINAL LASER TRIGGERING SYSTEM
NOTE: FIRST--RELAY RELEASE TIME
SECOND--TIME DURATION BETWEEN TWO BEAM INTERRUPTIONS

Raw Data (No.of Pulses)		Time Duration (seconds)	
First	Second	First	Second
99	883	0.6717	5.9913
102	883	0.6921	5.9913
101	884	0.6853	5.9981
101	885	0.6853	6.0049
100	883	0.6785	5.9913
101	885	0.6853	6.0049
100	884	0.6785	5.9981
100	884	0.6785	5.9981
101	885	0.6853	6.0049
101	885	0.6853	6.0049
101	884	0.6853	5.9981
101	885	0.6853	6.0049
100	884	0.6785	5.9981
101	885	0.6853	6.0049
101	885	0.6853	6.0049
100	885	0.6785	6.0049
101	885	0.6853	6.0049
101	885	0.6853	6.0049
101	884	0.6853	5.9981
100	884	0.6785	5.9981
101	884	0.6853	5.9981
102	885	0.6921	6.0049
101	883	0.6853	5.9913
98	882	0.6649	5.9845
102	885	0.6921	6.0049
100	884	0.6785	5.9981
101	885	0.6853	6.0049
101	885	0.6853	6.0049
100	884	0.6785	5.9981
100	885	0.6785	6.0049
101	885	0.6853	6.0049
101	885	0.6853	6.0049
100	884	0.6785	5.9981
101	885	0.6853	6.0049
102	886	0.6921	6.0117
99	882	0.6717	5.9845
101	885	0.6853	6.0049
100	884	0.6785	5.9981
101	885	0.6853	6.0049
101	885	0.6853	6.0049
AVERAGE		0.6829	6.0006
STANDARD DEVIATION		0.0056	0.0060
MAX		0.6921	6.0117
MIN		0.6649	5.9845
MAX RELATIVE VARIATION		0.0397	0.0045

DATA WERE TAKEN FOR MEASURING THE REPEATABILITY OF THE TRIGGERING SYSTEM
DATE : JUNE 29, 1988
CONDITION: CLOCK FREQUENCY = 1120.9 Hz
EQUIPMENT: 3010 FUN. GEN., LOW-SPEED MOTOR (10 RPM)
FINAL LASER TRIGGERING SYSTEM
NOTE: FIRST--RELAY RELEASE TIME
SECOND--TIME DURATION BETWEEN TWO BEAM INTERRUPTIONS

Raw Data (No.of Pulses)		Time Duration (seconds)	
First	Second	First	Second
774	6735	0.6905	6.0086
771	6732	0.6878	6.0059
768	6727	0.6852	6.0014
768	6727	0.6852	6.0014
767	6732	0.6843	6.0059
768	6727	0.6852	6.0014
768	6727	0.6852	6.0014
767	6727	0.6843	6.0014
779	6740	0.6950	6.0130
771	6713	0.6878	5.9889
769	6713	0.6861	5.9889
780	6729	0.6959	6.0032
755	6714	0.6736	5.9898
769	6740	0.6861	6.0130
764	6723	0.6816	5.9979
768	6727	0.6852	6.0014
767	6726	0.6843	6.0005
775	6736	0.6914	6.0095
770	6728	0.6869	6.0023
769	6728	0.6861	6.0023
770	6732	0.6869	6.0059
765	6724	0.6825	5.9988
768	6727	0.6852	6.0014
769	6728	0.6861	6.0023
766	6725	0.6834	5.9996
768	6726	0.6852	6.0005
770	6729	0.6869	6.0032
768	6727	0.6852	6.0014
778	6739	0.6941	6.0121
AVERAGE		0.6863	6.0022
STANDRED DEVIATION		0.0042	0.0059
MAX		0.6959	6.0130
MIN		0.6736	5.9889
MAX RELATIVE VARIATION		0.0325	0.0040

APPENDIX B

DATA COLLECTION PROGRAM AND DATA FROM TESTS USING PENDULUM DEVICE TO BREAK BEAM

```
10  '*****************************************************************
20  '*       This program designed by Tom E. Droz was used for       *
30  '* measuring the time duration between two signals from the      *
40  '* laser receiver.  A pendulum was used to break the laser beam  *
50  '* at precisely controlled intervals.  A TTL signal coming from  *
60  '* the relay of the radio receiver was interfaced to the         *
70  '* computer to provide a binary input to control starting and    *
75  '* stopping of the counter.                                      *
80  '*****************************************************************
85
90  REM initialize variables
100 ADAPT%=0:ID%=8:OD%=8:CD%=10:CHLO%=0:SETUP%=0:STAT%=0
110 PS%=&H7FFF:LAS%=15
115 OFFSET=6*65534+32767
120 GOTO 200
125
130 REM subroutines let the program wait for transitions from A/D
140 REM board
150 CALL BITINS (ADAPT%,ID%,LAS%,LAST%,STAT%)
160 CALL BITINS (ADAPT%,ID%,LAS%,FLAG%,STAT%)
170 WHILE LAST%=FLAG%:CALL BITINS (ADAPT%,ID%,LAST%,FLAG%,STAT%):WEND
180 RETURN
190
200 REM main program which counts the number of pulses
210 REM and outputs the result in form of seconds and
220 REM writes the pulse number in output file
230 GOSUB 1000
240 WHILE INKEY$=" "
250 GOSUB 150:CALL CSET (ADAPT%,CD%,CHLO%,SETUP%,PS%,STAT%)
260 GOSUB 150:CALL CINS (ADAPT%,CD%,CHLO%,SECOND%,STAT%)
270 GOSUB 150:GOSUB 150:GOSUB 150:CALL CINS
(ADAPT%,CD%,CHLO%,FINAL%,STAT%)
390 PRINT "final count  ";(OFFSET-FINAL%)*SCALE
300 GOSUB 150:CALL CINS (ADAPT%,CD%,CHLO%,LAST%,STAT%)
310 PRINT#1, OFFSET-FINAL%
320 WEND
330 CLOSE:END
340
1000 REM subroutine for opening an output file
1010 INPUT "enter clock frequency in Hz";Hz:scale=1/Hz
1020 INPUT "enter file name";F$
1030 IF F$="" THEN STOP
1040 IF INSTR(1,F$,".")=0 THEN F$=F$+".PRN"
1050 OPEN F$ FOR OUTPUT AS #1
1060 PRINT#1,Hz
1070 RETURN
```

DATA WERE TAKEN TO MEASURE REPEATABILITY OF THE TRIGGERING SYSTEM WITH A PENDULUM TO BREAK LASER BEAM AT PRECISE TIME INTERVALS.

DATE: AUGUST 3, 1988 5:45

CONDITION: CLOCK FREQUENCY =100930 Hz

EQUIPMENT 3010 FUNCTION GEN., 1803 100 MHz FREQUENCY COUNTER PORTABLE PERSONAL COMPUTER, FINAL LASER TRIGGERING SYSTEM, LASER RECEIVER #1

No. of Pulses	Time (Seconds)
421594	4.1771
421227	4.1735
421594	4.1771
421232	4.1735
421226	4.1734
421582	4.1770
421575	4.1769
421195	4.1731
421573	4.1769
421569	4.1768
421574	4.1769
421579	4.1769
421224	4.1734
421580	4.1770
421217	4.1734
421576	4.1769
421582	4.1770
421577	4.1769
421574	4.1769
421212	4.1733
421566	4.1768
421565	4.1768
421568	4.1768
421571	4.1769
421566	4.1768
421559	4.1767
421565	4.1768
421564	4.1768
421204	4.1732
421576	4.1769
421218	4.1734
421580	4.1770
421587	4.1770
421224	4.1734
421221	4.1734
421218	4.1734
421213	4.1733
421581	4.1770
421584	4.1770
421583	4.1770
421587	4.1770
421589	4.1770

421591	4.1771
421225	4.1734
421570	4.1769
421197	4.1732
421580	4.1770
421209	4.1733
421579	4.1769
421571	4.1769
421568	4.1768
421560	4.1768
421202	4.1732
421559	4.1767
421563	4.1768
421564	4.1768
421556	4.1767
421559	4.1767
421559	4.1767
421205	4.1732
421568	4.1768
421209	4.1733
421570	4.1769
421209	4.1733
421575	4.1769
421573	4.1769
421220	4.1734
421578	4.1769
421229	4.1735
421593	4.1771
421207	4.1733
421223	4.1734
421578	4.1769
421583	4.1770
421587	4.1770
421588	4.1770
421582	4.1770
421633	4.1775

AVERAGE	4.1758
STANDARD DEVIATION	0.0017
MAX VALUE	4.1775
MIN VALUE	4.1731
MAX RELATIVE VARIATION	0.0010

DATA WERE TAKEN TO MEASURE REPEATABILITY OF THE TRIGGERING SYSTEM WITH A PENDULUM TO BREAK LASER BEAM AT PRECISE TIME INTERVALS.

DATE: AUGUST 3, 1988 5:30

CONDITION: CLOCK FREQUENCY =100920 Hz

EQUIPMENT: 3010 FUNCTION GEN., 1803 100 MHz FREQUENCY COUNTER PORTABLE PERSONAL COMPUTER, FINAL LASER TRIGGERING SYSTEM, LASER RECEIVER #2

No. of Pulses	Time (Seconds)
421182	4.1734
421546	4.1770
421537	4.1769
421520	4.1768
421535	4.1769
421159	4.1732
421152	4.1731
421165	4.1733
421539	4.1770
421186	4.1735
421544	4.1770
421172	4.1733
421550	4.1771
421542	4.1770
421557	4.1771
421552	4.1771
421549	4.1771
421555	4.1771
421551	4.1771
421551	4.1771
421557	4.1771
421536	4.1769
421554	4.1771
421192	4.1735
421562	4.1772
421210	4.1737
421565	4.1772
421574	4.1773
421208	4.1737
421563	4.1772
421202	4.1736
421570	4.1773
421220	4.1738
421584	4.1774
421583	4.1774
421588	4.1774
421589	4.1775
421598	4.1775
421601	4.1776
421603	4.1776
421594	4.1775
421601	4.1776

421593	4.1775
421594	4.1775
421596	4.1775
421608	4.1776
421603	4.1776
421612	4.1777
421618	4.1777
421611	4.1777
421613	4.1777
421612	4.1777
421614	4.1777
421245	4.1740
421244	4.1740
421604	4.1776
421245	4.1740
421608	4.1776
421223	4.1738
421244	4.1740
421252	4.1741
421613	4.1777
421266	4.1743
421265	4.1742
421632	4.1779
421266	4.1743
421256	4.1742
421247	4.1741
421230	4.1739
421245	4.1740
421251	4.1741
421254	4.1741
421623	4.1778
421625	4.1778
421260	4.1742
421624	4.1778
421252	4.1741
421615	4.1777
421586	4.1774
421598	4.1775
421240	4.1740
421608	4.1776
421246	4.1741

AVERAGE	4.1761
STANDARD DEVIATION	0.0017
MAX VALUE	4.1779
MIN VALUE	4.1731
MAX RELATIVE VARIATION	0.0011

VITA

Jinliang Ren was born in Shihezi, Xinjiang, People's Republic of China on November 30, 1961. He attended elementary school and high school in Shihezi. In the fall of 1978, he entered Shihezi Agricultural College and received a Bachelor of Science degree in Agricultural Machinery in August of 1982.

After graduation from the college, he stayed at the same institution working as a teaching assistant. In 1985 he was selected by the college to study at the Beijing Foreign Language Center in preparation for continuing his formal education abroad.

In the fall of 1986, he enrolled at the University of Tennessee and began study toward the Master of Science degree in Agricultural Mechanization. This degree was awarded in December, 1988.

The author is a member of Gamma Sigma Delta, the honor society of agriculture.