THE UNIVERSITY OF MANITOBA

AN ULTRASONIC DEPTH SENSOR FOR TILLAGE IMPLEMENTS

by

Karanbir Singh

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

DEPARTMENT OF AGRICULTURAL ENGINEERING

WINNIPEG, MANITOBA

June, 1982

AN ULTRASONIC DEPTH SENSOR FOR TILLAGE IMPLEMENTS

BY

KARANBIR SINGH

A thesis submitted to the Faculty of Graduate Studies of the University of Manitoba in partial fulfillment of the requirements of the degree of

MASTER OF SCIENCE

Abstract

An ultrasonic depth sensor
for tillage implements

by

Karanbir Singh

A depth sensing unit was developed by modifying a Polaroid ultrasonic range finding unit to measure the depth of tillage operation in analog form. The depth sensor was tested under simulated field conditions and performed with an accuracy of ±3 mm.

The depth sensor was calibrated on a variety of surfaces to establish a relationship between the output voltage and the simulated depth of tillage by utilizing linear regression. This was helpful in examining not only the linear relationship between the output voltage and the depth of tillage but the effect of the surfaces as well. The calibration data also established a base to check the validity of data from the simulated field conditions. The depth sensor was also tested for its practical application by determining the effects of dust, transducer tilt, tractor noise and stubble ground cover. The sensor performed satisfactorily under all conditions except when operating in stubble conditions.

ACKNOWLEDGEMENTS

I wish to express my sincere gratitude and indebtedness to Professor L.C. Buchanan for his kind guidance and encouragement throughout the course of this study. Sincere thanks are extended to Dr. G.E. Laliberte, Dr. M.G. Britton, Dr. S.Y. Reitsma and Professor A.W. DeGroot for their interest and involvement in the project.

Appreciation and thanks are also extended to Mr. Allan McKay, Mr. Ken Biegun, and Mr. Ken Podaima of the Department of Electrical Engineering and Mr. J.G. Putnam, and Mr. R.H. Mogan of the Department of Agricultural Engineering, for their technical help in conducting this study.

I would also like to extend my sincere appreciation and deepest indebtedness to my father Ram Pal for his sacrifices, patience and understanding during the course of this study.

The author is grateful to the Manitoba Department of Agriculture for financial support to this project.

TABLE OF CONTENTS

Page

LIST OF FIGURES (TEXT)

LIST OF FIGURES (APPENDICES)

LIST OF TABLES (TEXT)

CHAPTER I

INTRODUCTION

As the present trend shifts to larger field machines on farms in western Canada, there is a growing need for automatic controls or at least systems which allow the operator located on the tractor to monitor the performance of machines. The larger machines are either single trailing units equipped with fold-up wings operating abreast or multiple units operating in an offset-tandem fashion. In any event the machines are quite remote from the operator, making it difficult (for him or her) to judge the operating depth and operate the hydraulic valves accordingly as field conditions change.

It is desirable from the standpoint of energy as well as production considerations to monitor and maintain a constant depth of tillage and seeding operation. Variations in the operating depth may occur due to changes in the soil density, moisture content, percentage of trash in the soil and the loading of the seeding implement with grain and fertilizer. Efforts to compensate for these variations and regulate the depth are limited to the ability of the operator not only due to the distance but also due to a variety of reasons such as obstruction of view, dust and lack of light. Operator's fatigue may also be considered as a factor in continuously controlling the depth.

To accommodate variations in the operating depth, farmers tend to operate their machines deeper than is necessary. If the tillage machine is operating at a depth in excess of that required for an effective weed control, it will involve a higher cost because of an increase in the draft. Although this cost is not significant in terms of present day operating cost, it may soon become important as petroleum resources diminish and the attention becomes more focused on the energy consumption in agriculture.

Tillage and seeding operations are important and would benefit from an efficient automatic depth control system. An automatic depth control system should perform the following functions:-

(1) It should generate a signal proportional to the depth of operation of the implement.

(2) It should generate an error signal by comparing the actual signal with a reference signal.

(3) It should regulate hydraulic cylinders according to the error signal.

The automatic control system may be divided into two steps: the monitoring or sensing part and the control unit relying on the monitor feedback. Only the monitoring part was considered in this investigation which will serve not only as step one in the overall problem but also can be used as a visual indication of the operating depth for the operator in the tractor cab.

The objective of this work was to develop and test a depth sensing unit by modifying a range finding unit of a Polaroid camera so that it will display an output signal proportional to the depth of tillage and seeding operations. The unit was tested to determine the following:-

(a) The relationship between the output voltage and the depth of tillage on sandy loam bed 40 mm thick, 1% moisture content ODB*, clay bed 40 mm thick, 8.4%, and 50.2% moisture content ODB and peat soil bed 40 mm thick, 253.3% moisture content ODB as well as some unrelated surfaces such as plywood (60 cm x 60 cm x 1.25 cm), steel (60 cm x 60 cm x 0.1 cm) and water (60 cm x 60 cm x 4 cm).

(b) Effect of dust, transducer tilt, tractor noise and stubble (trash).

(c) Dynamic response and performance under simulated conditions.

The depth sensor mounted on an implement monitors the depth of tillage operation as an analog signal indicated by a dial gauge.

---

*ODB: Oven Dry Basis

CHAPTER II

REVIEW OF LITERATURE

2.1 Significance of Depth of Seeding and Tillage

Placement of seeds at a proper depth in the soil is very important for an optimum yield of the crop. Too shallow or deep placement of seed results in a reduced yield (cited by Kilcher et al. 1970, Larter et al. 1955). It is well understood that the depth of seeding or tillage will affect the draft and in turn change the tillage energy requirement. Dransfield et al. (1964) and Harrison et al. (1962) also conducted tests that illustrated the proportionality of the draft to the depth of tillage.

The depth of tillage also affects the plant residue and trash covering the soil surface. The amount of plant residue or trash left on the soil decreases as the tillage depth increases (Fenester 1960, Anderson 1964, 1965). Plant residue or trash protects the soil from erosion and helps to conserve soil moisture by reducing the exposed area of the soil to the sun. Trash aids in holding the winter snow on the field and conserves moisture (Radhey and Steppuhn 1979).

2.2 Depth and Draft Controls

Normally, the operating depth of trailing implements is controlled manually by the operator. The operator manipulates and positions a hydraulic directional control valve by operating a lever. The control valve directs the hydraulic fluid to and from hydraulic cylinders, mounted on the implement, thus raising or lowering them in relation to a set of transport wheels.

In some cases, the depth of operation of tractor-mounted implements is automatically controlled by controlling the draft. Cowell et al. (1967) determined that at lower speeds the mounted implements gave better performance when the depth was automatically controlled by gauge wheels rather than being controlled by the draft, thus an automatic depth control system which is based on the depth, will give a better performance.

In addition to relieving the operator of the task that requires a good deal of judgement as well as endurance, a depth control unit will also help to save energy by maintaining a constant depth of operation.

Tillage energy can be evaluated (Wendte and Rozeboom 1981, Smith et al. 1981) in order to determine the effect of depth on the tillage energy requirement. To maintain a constant depth, there is a need for the development of a depth control unit. Some work has been done on automatic depth controls.

Hook (1968) developed a complete operator control system with a single lever at the tractor seat with no other mechanical adjustments. It utilized hydraulic cylinders to control the depth by adjusting gauge wheels. Three cylinders, connected in series with a hydraulic by-pass system in each cylinder were mounted on the implement. The by-pass system helped to control the depth by by-passing the fluid and adjusting the hydraulic cylinders accordingly. The series arrangement performed properly while the parallel arrangement did not give a good response.

Hook et al. (1970) also tried to develop a system for integral flexible implements by utilizing hydraulic cylinders. The draft and depth response for the integral implements plus an additional tractor hitch lift were obtained with a single lever hydraulic control system, utilizing the tractor's three point hitch. Out-rigger gauge wheels were actuated by hydraulic cylinders connected with the tractor rock-shaft cylinder. The hydraulic system was actuated by diverting the rock-shaft hydraulic fluid to the out-rigger series cylinders and then returned to the tractor cylinder.

Advantages of this system were that heavy implements could be attached to it, extra lift capacity was obtained and the tractor front end as well as lateral stability was improved by support provided by the implement out-rigger wheels. Field experiments verified that integral flexible implements were compatible with the trend to tractors with higher ratio of power to mass.

Sweet et al. (1969) developed a system to control the depth by using gauge wheels. In this system, there was a relative displacement between gauge wheels and the implement frame position in response to the change in the depth. This relative displacement was utilized to operate the hydraulic cylinder which adjusted the depth accordingly, with the help of a linkage system between gauge wheels and the implement frame. This system involved a complicated linkage but performed properly.

Jeannotte (1971) developed a system for integral flexible -ganged disc-blade implements by using a rubber tired wheel for each gang. The principle of operation of this system was the same as described for the system developed by Sweet et al. (1969). The performance of this system was also reported satisfactory.

Dyck (1975) made use of a ski-shoe type member and developed a system to control the depth. The ski-shoe and a gauge wheel provided a relative displacement in response to the change in the depth. A potentiometer, mounted on a member of the ski-shoe and connected to a member of the gauge wheel with a spring tensioned cable wound around its shaft, rotated in response to the depth of operation. The output signal was proportional to this depth. It had an "Auto-Manual" selector switch to permit the operator to manually operate in rough fields and to set on "Auto" in even ground conditions to adjust the depth automatically. A damping cylinder which moved according to depth changes controlled the limit switch to actuate a solenoid valve for automatic control of the hydraulic system. This system worked well during the field trial up to a speed of 5.6 km/h with a maximum error in the depth of around ±8.9 mm, but it was not able to control the depth to the desired limits at higher speeds.

A fluidic transducer was also utilized to control the tillage depth (McLaughlin et al. 1976). It consisted of a pretensioned helical spring. The spring was plugged at one end and connected to the ski-like member, mounted between the cultivator shanks. A change in the cultivator depth caused the spring to be bent, allowing the escape of the compressed air provided by an air supply. The air flow through the spring transducer was measured with a fluidic resistance bridge arrangement which compared the actual signal with a reference signal and operated the hydraulic system accordingly. To provide an averaging effect, four spring transducers were connected in parallel to the air supply. The maximum error in the depth was reported as 6.6 mm while the static dead zone was kept as 6 mm.

A prototype automatic depth control system, using ultrasonic transducers, was introduced by Paulson and Grimm of the Division of Control Engineering, University of Saskatchewan, Saskatoon (Zoerb et al. 1977). It had an advantage over the previously existing systems because it did not have the ski-shoe like member and could be operated in trashy conditions. The system utilized ultrasonic transducers mounted at various points on the discer to generate a signal that was proportional to the average depth of the operation. By comparing this signal with a reference signal a control signal was produced that activated an electro-hydraulic valve on the discer depth control system.

Small (1978) developed an on-off system, for onion harvesters, which incorporated some of the features of earlier developed systems. In this unit, an under-cutter knife was mounted on a boom which was supported by wheels. A ski-shoe sensor was directly connected to two adjustable contacts and slid on the onion surface. The contacts were adjusted to a desired cutting depth and floated in a dead zone between the limit switches. As there was a change in the depth of onion cutting, a contact actuated one of the two limit switches. The switch actuated a hydraulic solenoid valve to operate the hydraulic depth control cylinder which in turn raised or lowered the knife as required. The limit switches were mounted on the frame of the knife and provided an automatic feedback.

This system had an advantage of having an override locking system to lift the implement at the end of the row without disconnecting the electrical power supply to the limit switches. This system however experienced problems in controlling the depth when operating in clods or lumps. A dead zone of approximately $\pm$20 mm could be maintained by this system.

Most of the systems described above were mechanical linkage units. These systems were a logical step in the development of depth controls; however, their commercial success seemed to be limited by the technique itself (cited by Paulson, Strelioff 1974). The ultrasonic system developed by Paulson and Grimm (reported by Zoerb et al. 1977) brought some new ideas in the field of depth control systems.

2.3 Depth Measurement

It is important while performing tillage operations that the operator should know the depth of operation to ensure a proper depth controlled either manually or automatically. Some systems which are used to control depth, can also be used to display its value by a depth equivalent signal. For example, the system designed by Dyck (1975) was used to control the depth (Section 2.2) but the potentiometer of this system could also be used to display the depth of operation. Gabrilides (1962) developed a similar system to indicate the depth and this system performed properly up to the speed of 7 km/h.

Paulson and Strelioff (1974) developed an ultrasonic depth sensing unit by using ultrasonic sensors. These sensors were mounted on the frame of a cultivator measuring the time required for an ultrasonic burst to travel down to the soil surface and for its return. The time dependent output was displayed in an analog form which was proportional to the depth of the operation. Reference transducers were used to compensate for the effect of temperature and the temperature sensitivity was reduced to 0.06% per ^{o}C.

Wendte and Rozeboom (1981) designed a system which used a linear variable differential transformer (LVDT) to produce a signal proportional to the depth of operation. A change was made in the LVDT by shifting the zero voltage reading from the centre of the LVDT stroke to the upper end. It produced a maximum voltage of six volts at the maximum stroke of 254 mm. The stroking action in the LVDT was caused by a simple mechanical linkage connected between the LVDT and a bogie wheel which travelled on level ground. A laboratory test indicated a 0.25% non-linearity for the LVDT.

CHAPTER III

THEORETICAL CONSIDERATIONS

3.1 General Description

The Polaroid ultrasonic ranging unit, designed by the Polaroid Corporation for use on their cameras is comprised of two components; an acoustical transducer (Figure 1) and a Polaroid ultrasonic ranging circuit board (Figure A.1.1, A.1.2). Together these two components are capable of detecting the presence and measuring the distance of objects within a range of approximately 0.28 m to 10.68 m.

When the unit is activated, the transducer emits a sound burst, then waits to receive the echo returning from whatever object the sound pulse strikes. The elapsed time between the initial transmission and the echo detection is then converted to a distance with respect to the speed of sound. The conversion of time to distance is performed by two circuit boards. The digital circuit board (Figure A.1.3) converts the elapsed time into the equivalent distance in the form of a digital signal and the analog circuit board (Figure 3) converts it into analog form.

The emitted burst is a high frequency, inaudible "Chirp," lasting for one millisecond and consisting of fifty-six pulses at four carefully chosen ultrasonic frequencies; 8 pulses at 60 kHz and 57 kHz, 16 pulses at 53 kHz and 24 at 50 kHz. Occasionally, a single frequency could be cancelled because of certain topographical characteristics, thus four echo frequencies are useful to overcome this obstacle.

All four components; the transducer, the Polaroid ultrasonic ranging circuit board, the digital circuit board and the analog circuit board, are enclosed in a portable box and this whole unit is necessary to perform the depth measurements.

3.2 Transducer

The principal component in this device is the transducer (Figure 1) which acts as both loudspeaker and microphone. It has been designed to transmit the output signal and also to function as an electrostatic receiver in order to receive the reflected signal (the echo). Its diameter determines the acoustical lobe pattern, or acceptance angle, during the transmit and receive operations.

A special manufactured foil is stretched over a grooved plate, forming a moving element which transforms the electrical pulses into sound waves and transforming the echo back into an electrical signal. The grooved metallic back-plate in contact with the foil stretched over it forms a capacitor with the foil and when charged exerts an electrostatic force to the foil which in turn vibrates and produces sound waves (bursts). A 300 V signal is applied across the transducer

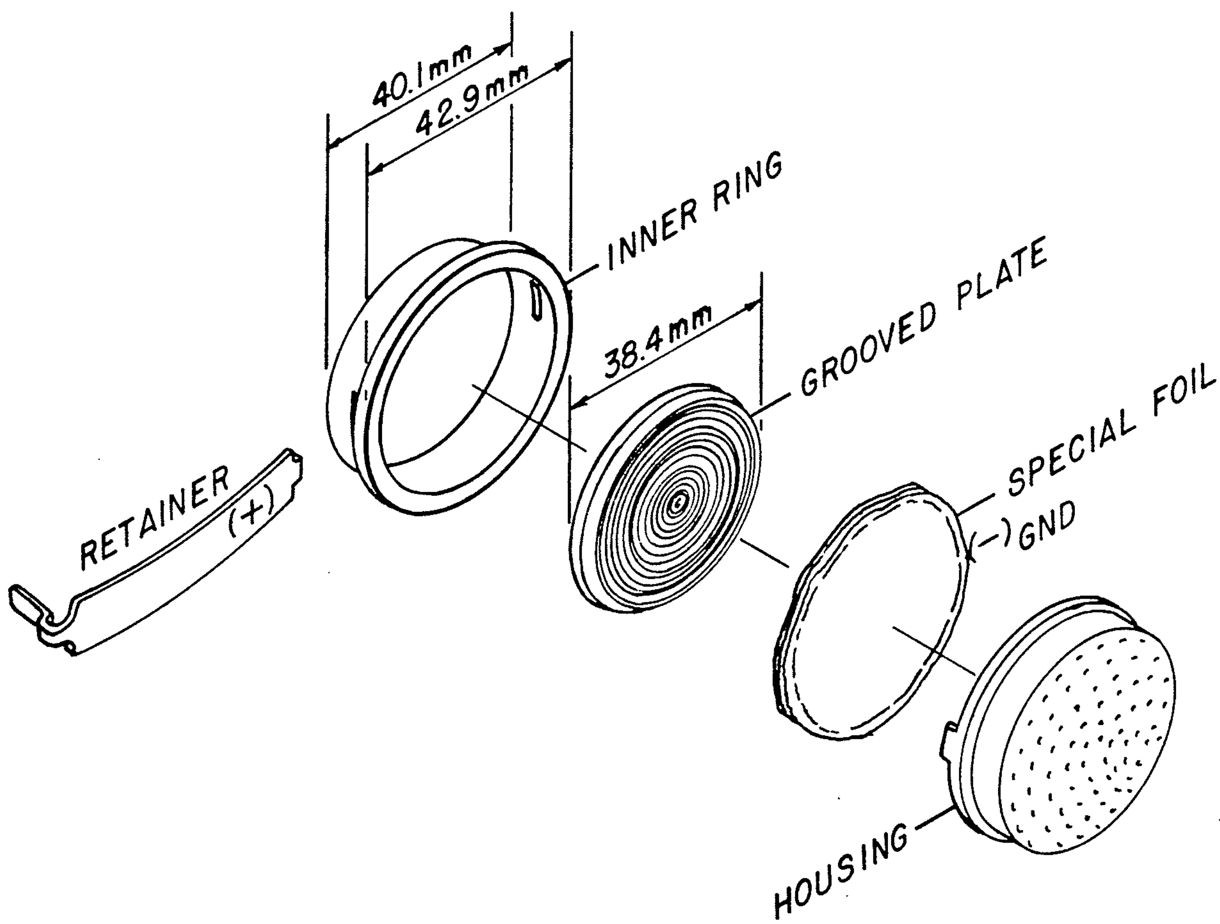


Figure 1. Components of the transducer (courtesy of the Polaroid Corp.).

to produce and transmit a "chirp." This voltage gives a noticeable, but harmless shock.

The foil is pliable, capable of resisting a harsh environment and is an excellent electrical conductor. The terminal of the foil is grounded and connected to Pin 1 and the other terminal of the transducer (connected to the grooved plate) is connected to Pin 2 (Figure A.1.1, A.1.2). The transducer operates satisfactorily at temperatures from $0^{o}C$ to $60^{o}C$ and a relative humidity of 5% to 95%.

3.3 Polaroid Ultrasonic Ranging Unit Circuit Board

The second component of the Polaroid ranging unit is a Polaroid ultrasonic circuit board (Figure A.1.1, A.1.2). This board contains a circuitry which controls the operating mode (Transmit/Receive) of the transducer. It is comprised of three major sections which control the transducer operation: a digital, an analog and a power interface section.

The power supply required for this circuit is from 4.5 to 7 Vdc capable of 1 ms current surges of about 2.5 A. An appropriate drive circuit (Figure A.1.3; Pin 9) initiates the transmission of an ultrasonic burst by the transducer by supplying a switching power (VSW) to this circuit at four pulses per second. A crystal-controlled clock in the digital section generates the ultrasonic frequencies (56 kHz i.e. 8 pulses at 60 and 57 kHz, 16 pulses at 53 kHz and 24 pulses at 50 kHz) that comprises the burst (lasting for one ms) by the transducer.

3.4 Experimental Circuit Boards

Experimental circuit boards are used to display the information gathered by the Polaroid ultrasonic ranging unit in the form of a digital or analog signal. The original circuit board had a 3-digit display with a resolution of 3 cm (Figure A.1.3) and is augmented with an analog output (Figure 3,4). The digital circuit board operates om 4.5 to 7 Vdc and provides the Polaroid ultrasonic ranging circuit board with a switching voltage (VSW), a constant plus voltage and a ground return. The Polaroid ultrasonic circuit board provides the digital board directly with the transmit signal (XLG) and the received echo signal (FLG) (Figure 2).

XLG is the digital logic drive for the transmitted signal and FLG is the signal which indicates that the reflected transmitted signal is received. A time window (echo time) directly related to the distance is generated by the transmitted signal (XLG) and the detected (received) echo (FLG). A 420 kHz clock on the digital board (Figure A.1.3) allows accurate measuring of this window. The VSW applied to the Polaroid ultrasonic circuit board causes it to transmit and receive the echo repeatedly providing a new time window each cycle. After each cycle, the digital circuit board measures the time window and converts this into distance in a digital form which is displayed.

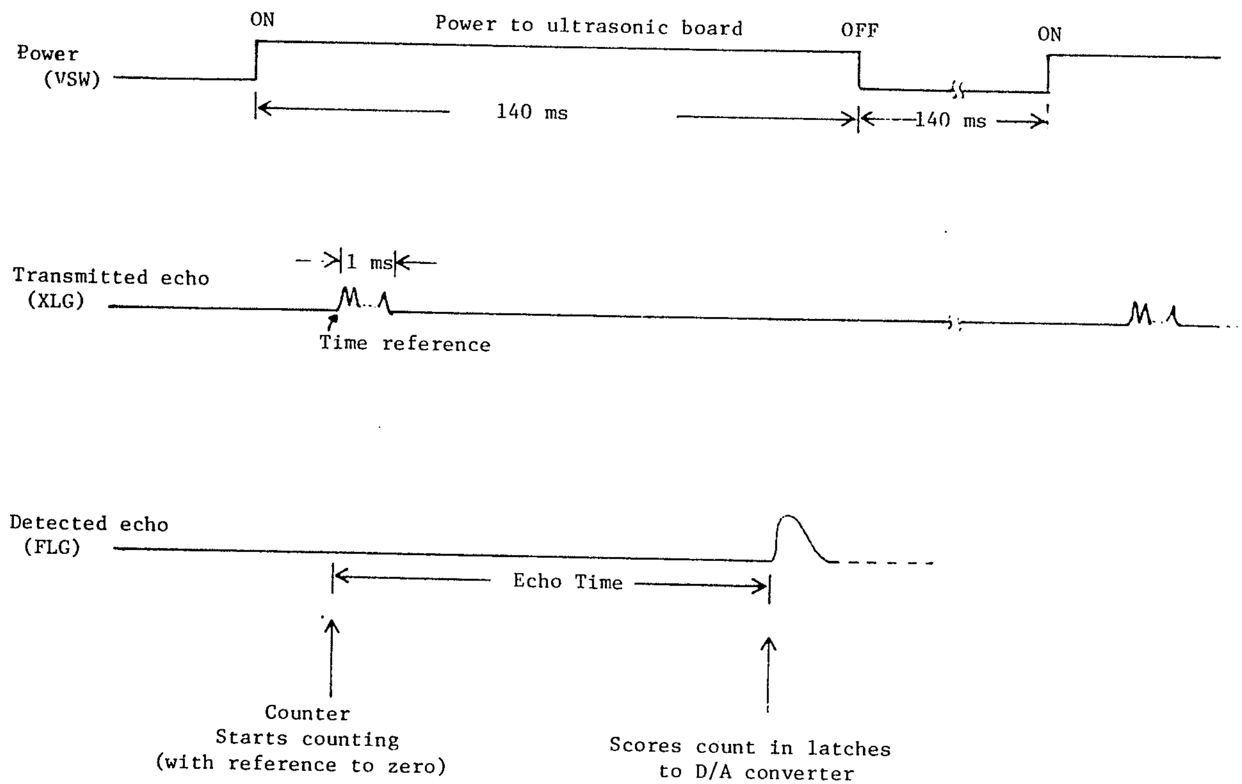


Figure 2. Wave forms showing the time window generated due to a transmitted and reflected sound burst.

Figure 3 illustrates the analog circuit designed for a 4.5 to 7 Vdc power source. Two voltage regulators (MC7805) are incorporated to convert 12 Vdc (tractor battery) to ± 5 Vdc to operate the circuitry. One regulator supplies power to the digital circuit board and another to the analog circuit board to prevent interferences.

The analog circuit board generates an output voltage dependent on the depth of tillage. For this circuit a 12-bit counter (14040B) is chosen to monitor the echo time. Only 10 bits of the counter are used to satisfy the required working conditions. The triggering option of the time (LM555) is utilized to execute the counting of the echo time. The following calculations show the suitability of the counter for the required working conditions:

Velocity of sound at $20^{o}C$ = 342 m/s

The height of the transducer from the ground = 45 cm

The time required for the echo burst to travel (2 x 45 cm) $= \dfrac{2 \times 45 \text{ cm} \times 10^{3} \frac{\text{ms}}{\text{s}}}{100 \frac{\text{cm}}{\text{m}} \times 342 \text{ m/s}}$

$= 2.63$ ms

The maximum count of the counter = 1023

The period (T) of the oscillator

$T = 0.693 (R_1 + R_2) \times C_8$

The frequency of the timer $f = \frac{1}{T}$ where R_1, R_2 and C_8

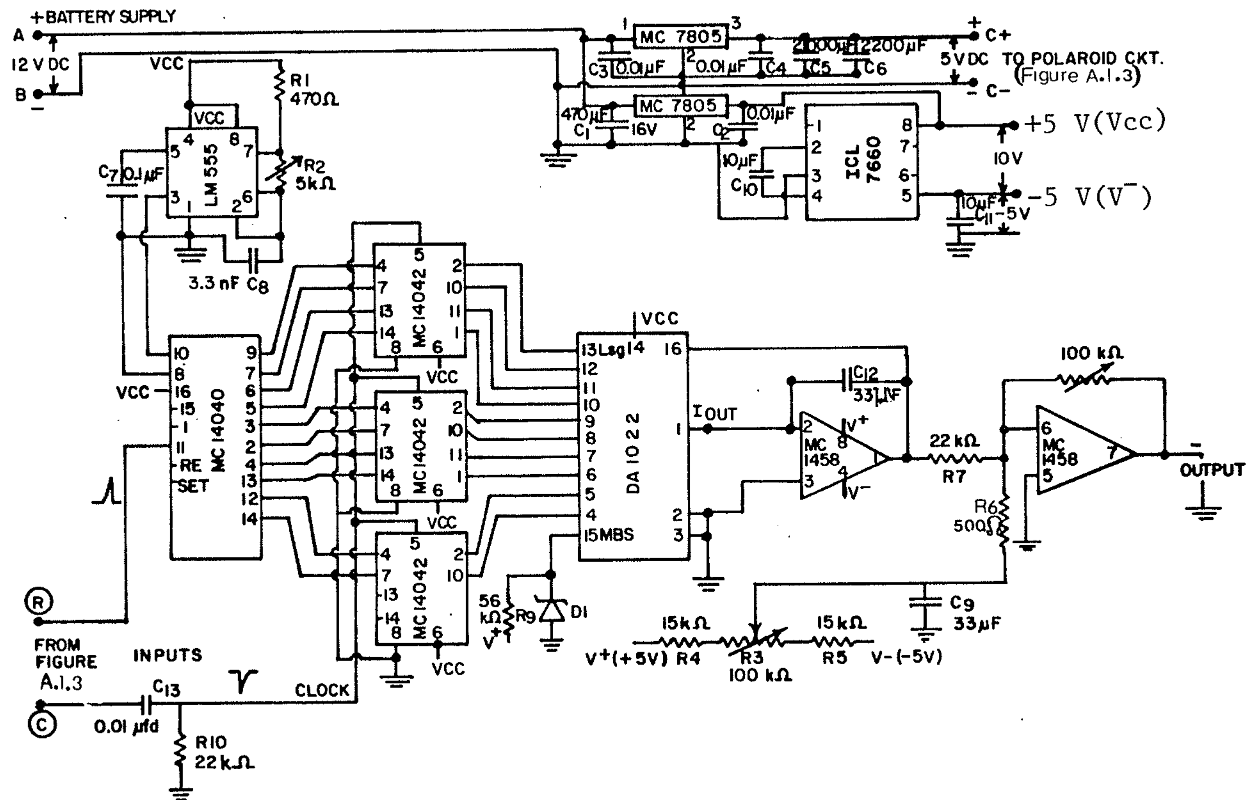


Figure 3. The circuit of the analog circuit board.

are shown in Figure 3. Thus the maximum and minimum clock frequencies calculated from above could be 930 and 42 kHz which would provide minimum and maximum time (1023/f) required to exceed counts of the counter as 1.1 and 24.5 ms. The time of the burst (2.63 ms) to travel (2 x 45 cm) is in the above stated time range (1.1 to 24.5 ms) which could be adjusted through resistor R_2 (Figure 3,4). For all the experiments in this thesis the timer frequency was adjusted to 152 kHz which provided a maximum response time of 6.74 ms. This corresponds to a time interval greater than that necessary for the sound wave to travel twice the 45 cm distance. The reset R and point C from Figure 3 were connected to point R and C (Pin 13 and Pin 10 respectively of MC14553 Figure A.1.3) in the digital circuit board.

At the end of each cycle the state of the counter is stored in the 10 bit latch (MC14042B) and is held until the next cycle update. A 10 bit binary multiplying digital to analog converter (DAC1022) converts the digital count into an analog signal. A dual operational amplifier (MC1458B) provides averaging and inverting functions to the analog output. The offset and the gain can be adjusted by means of resistors R_3 and R_8 respectively. The overall operation of the analog circuit can be summarized as follows:

(1) As the echo-burst is transmitted, the signal XLG R starts the counter (14040B) from a count of zero

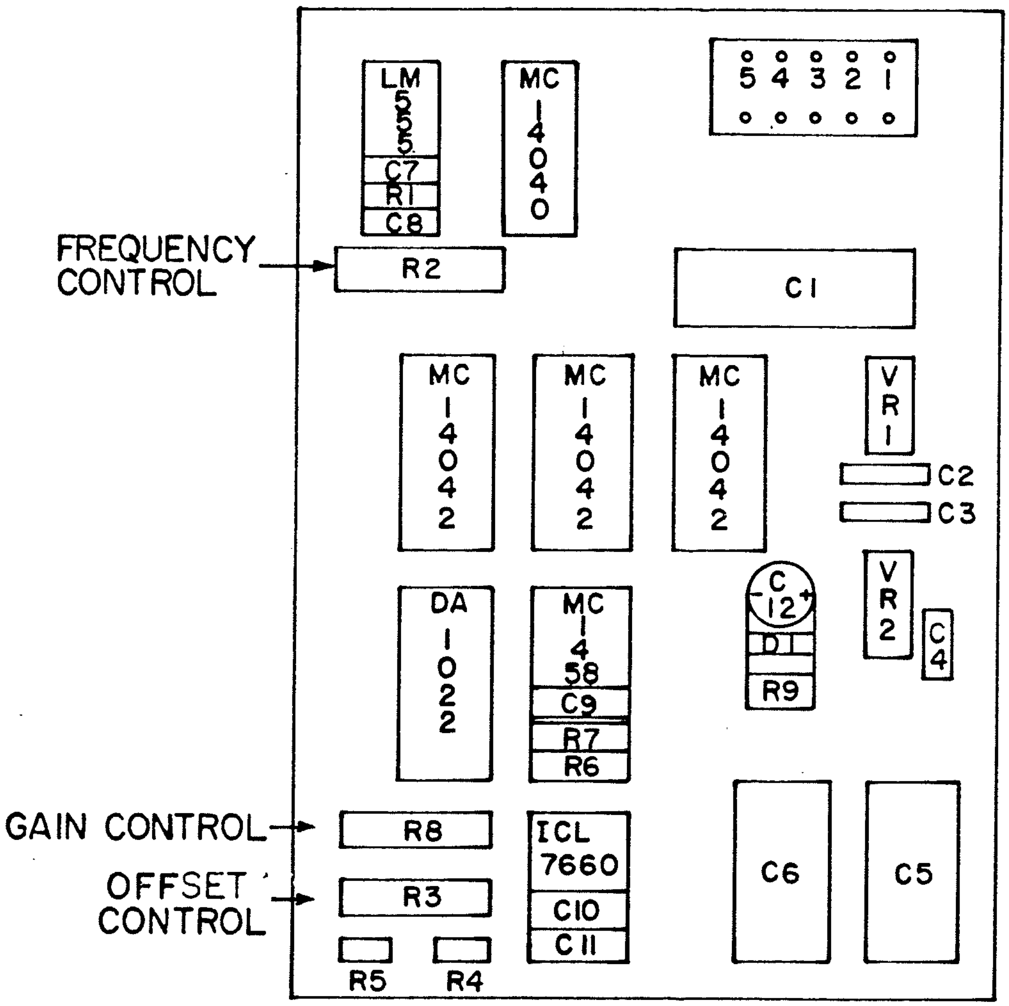


Figure 4. Component layout of the analog circuit board.

to perform the echo time determination.

(2) when the reflected echo is received, the signal FLG C activates the latches to store the state of the counter.

(3) The DAC 1022 converts the count held in the latches analog form.

(4) The output analog signal from DAC1022 is inverted and averaged out by an amplifier (MC1458B). The time constant of the filter in the averager is 0.5 s.

Figure 5 shows the overall block diagram of the depth sensor including all the stated components in this chapter.

3.5 Effect of Travel Speed

The sound burst transmitted from the transducer is received after it is reflected back from whatever object it strikes. Each burst is comprised of fifty-six pulses and the pulses which travel the shortest distance return first and activates the circuitry. The shortest distance travelled by any pulse will be twice the perpendicular distance between the transducer and the object. If the transducer is not stationary, the shortest distance would be the same as stated above and the speed of travel would not make any difference until the reflected sound burst is received at the transducer. If the transducer speed is such that the reflected sound burst is just received it would be called a critical speed of travel and above this speed the sound burst might not be

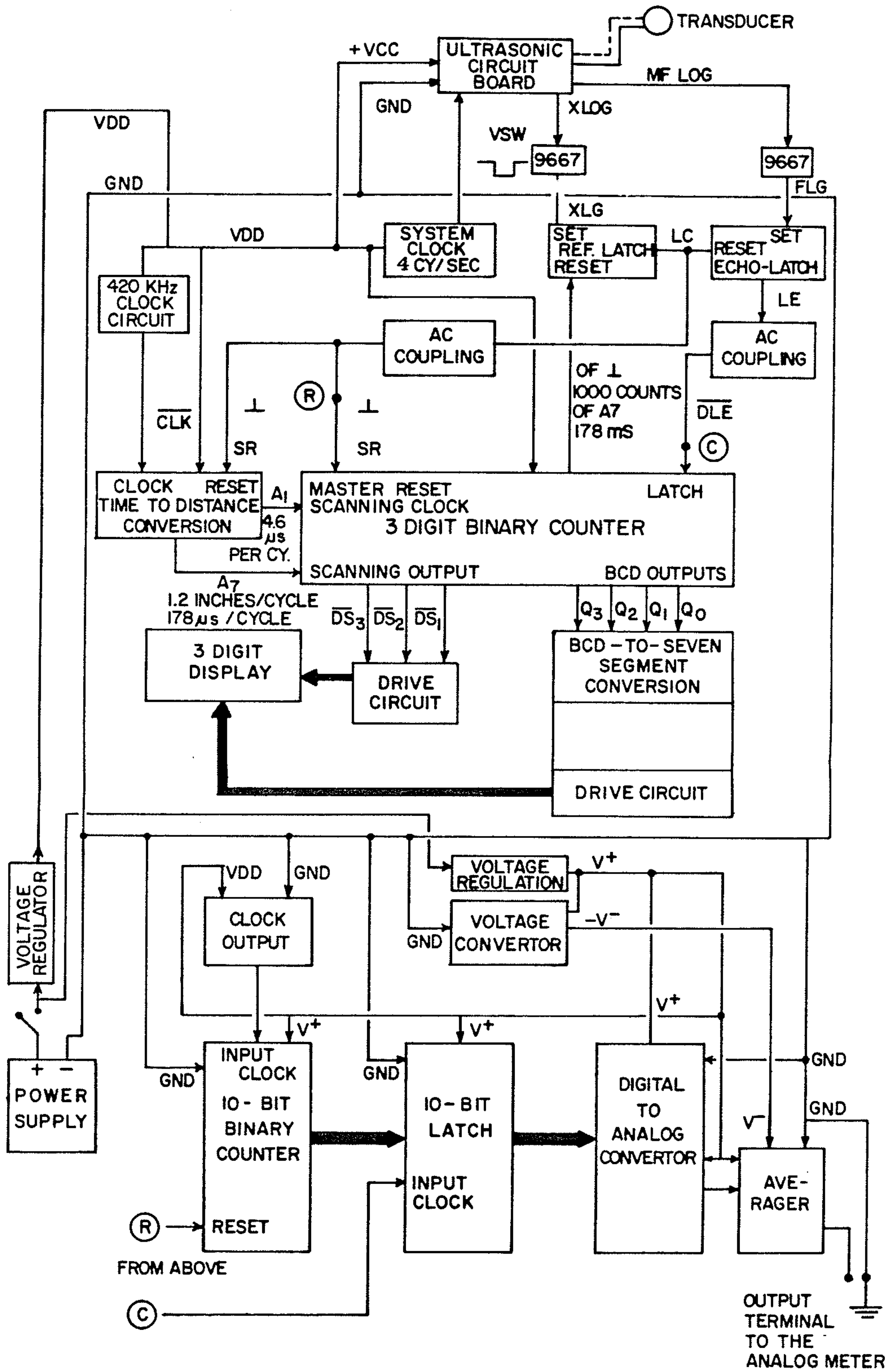


Figure 5. Block diagram of the depth sensor.

received at the transducer. In this kind of situation, the output of the depth sensor would indicate an erroneous result.

The critical speed of the transducer travel could be evaluated by dividing the foil diameter (Figure 1) by the echo time since it might be assumed that at the critical speed the sound burst transmitted from the front of the transducer should be received at its rear, i.e.

$$Vc = \frac{D \text{ mm} \times 3600 \text{ s/h}}{t \text{ ms} \times 10^{-3} \text{ s/ms} \times 10^{6} \text{ mm/km}}$$

where: Vc = The critical speed of the transducer (km/h)

D = Foil diameter (38.4 mm)

t = The echo time (2.63 ms)

Thus the critical speed calculated could be given as 52.5 km/h which is much higher than the operating speed of tillage implements. It can be concluded that the conventional operating speed will not affect the accuracy of the depth sensor.

3.6 Effect of Temperature

The output of the depth sensor is dependent on the environmental temperature because of the change in velocity of sound. The velocity of sound is proportional to the square root of the absolute air temperature (Winstanley 1952), i.e.

$$\frac{v_1}{v_2} = \sqrt{\frac{T_1}{T_2}}$$

where v_1 and v_2 are the sound velocities at T_1 and T_2 absolute air temperatures. The relationship between the sound velocity and the output voltage could be derived since the output voltage (at DA1022) would be proportional to the echo time and hence inversely proportional to the sound velocity, i.e.

$$\frac{v_1}{v_2} = \frac{V_2}{V_1} = \sqrt{\frac{T_1}{T_2}}$$

where V_1 and V_2 are the output voltages at T_1 and T_2 absolute air temperatures. If the reference air temperature is 20^oC (i.e. $T_1 = 293^oK$), ± 3.4 and $\pm 5.8\%$ ($T_2 = T_1 \pm 10$ and $T_2 = T_1 \pm 20$ respectively) variation in the reference temperature would produce a maximum of ∓ 1.8 and $\mp 3.6\%$ variation (error) in the output voltage at DA1022.

CHAPTER IV

EXPERIMENTAL PROCEDURE

4.1 Introduction

Various experiments were conducted to determine the feasibility of using the depth sensor to predict the depth of tillage or seeding operation. Firstly, the unit was calibrated at room temperature (25°C) on a plywood 60 cm x 60 cm x 1.25 cm, steel plate 60 cm x 60 cm x 0.1 cm, water 60 cm x 60 cm x 4 cm, sandy loam bed 40 mm thick, 1.0% moisture content ODB*, Red River clay bed 40 mm thick, 8.4 and 50.2% moisture content and peat soil bed 40 mm thick, 253.3% moisture content ODB so that the effect of various surfaces on the output could be established. A digital voltimeter was used to record the output.

Secondly, tests were performed under simulated field conditions as to ensure and establish the feasibility of using the depth sensor to accurately monitor the depth of tillage operation. A soil bin was utilized to carry out the simulated field tests. A recorder (Fisher Recordall series 5000) was used to record the output on the go for various tests on the soil bin.

---

*ODB = Oven Dry Basis

The simulated field tests were performed to determine the effect of dust, implement tilting, tractor noise and stubble ground cover as well as to examine the dynamic response and performance of the depth sensor for the simulated depth of tillage (sections 4.3 to 4.7). In all tests, the depth sensor was operated by a 12 V tractor battery.

4.2 Calibration Method

The objective of the calibration was to determine whether surface material would affect performance of the depth sensor and also to provide a basis for comparison of data under simulated conditions. The calibration was carried out with the help of a stand (Figure 6) by which the transducer could be adjusted to various heights from the ground which provided a simulated condition for depth of tillage. Output readings were taken at one cm height intervals while lowering and raising the transducer. Output readings for these surfaces are shown in Table 2. A SAS (Statistical Analysis System) program (Appendix B.1) was utilized to perform the linear regression of data for each surface. Another program (Appendix B.2) performed the linear regression of the pooled data in which all the data of Table 2 were combined to get an accurate regression line.

4.3 Dust Interference Test

To simulate a field operation dust condition, a shop

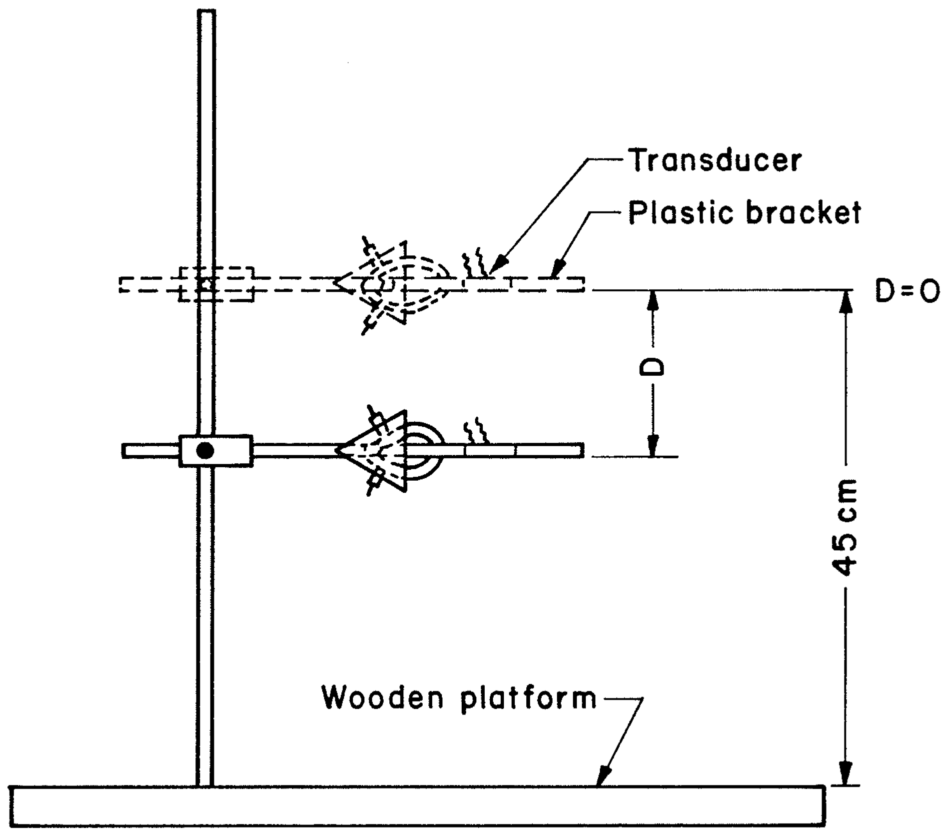


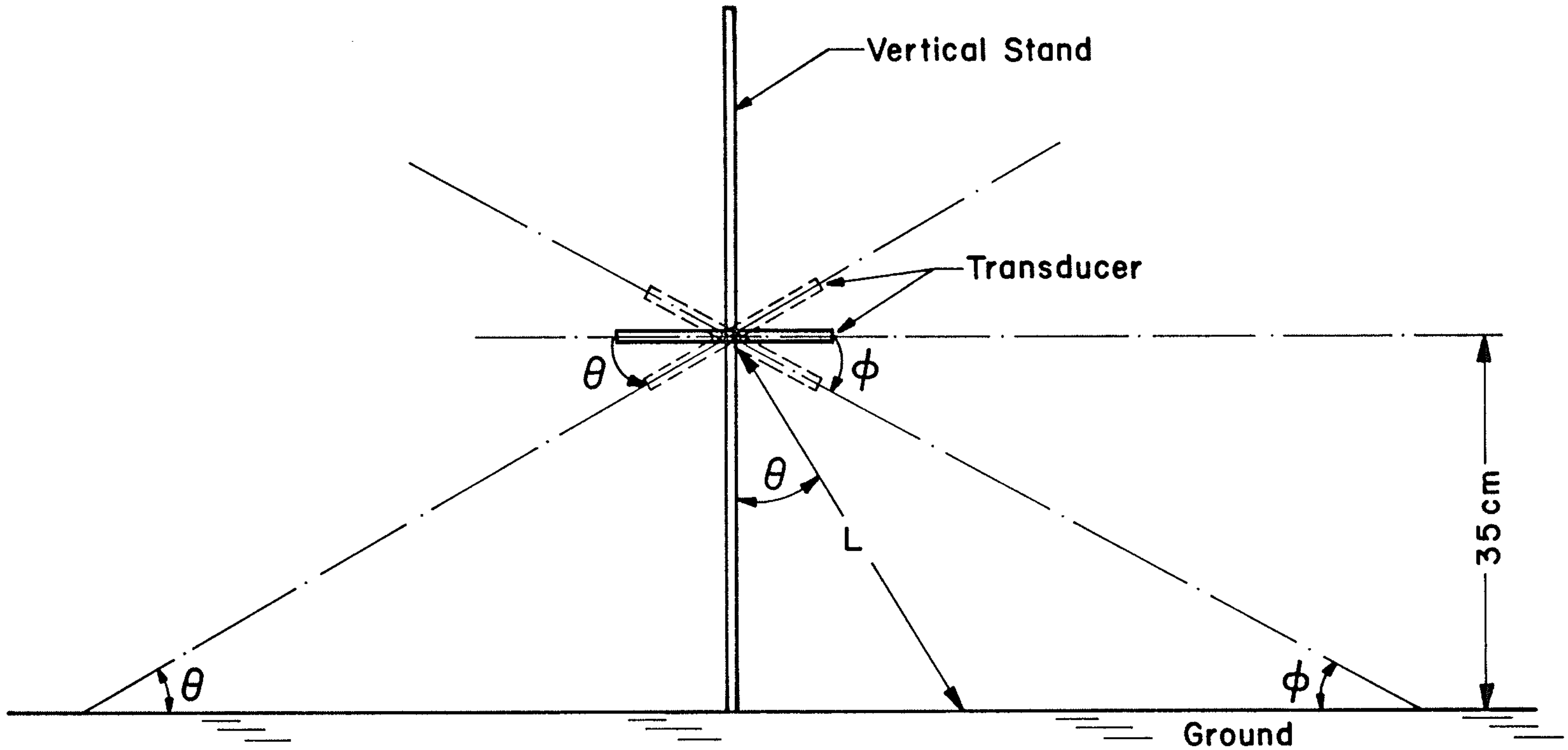
Figure 6. The stand used for the calibration of the depth sensor illustrating the simulated depth of tillage (D).

vacuum was used to pick up soil from the soil bin and discharge it into a polyethylene enclosure surrounding the transducer. The height of the transducer was maintained at 45 cm during the test and the output was recorded (Figure 11) on the chart.

4.4 Transducer Tilting Test

During field operation there is some possibility that implement tilting may cause the transducer to sense a false distance and hence it would indicate a false reading. This aspect was checked at various angles of implement tilt and compared with the output calculated from the theoretical distance sensed by the transducer. This will not only illustrate the effect of the transducer tilting but also the effect on the distance sensed compared with the distance calculated (theoretical) from the triangle formed due to the transducer tilting.

Figure 7 shows the apparatus for adjusting various angles of tilt. The height of the transducer was kept as 35 cm assuming the depth of tillage operation to be 10 cm (section 4.2) for zero angle of tilt (solid lines). In order to simulate the implement tilting situation, the transducer was rotated in the vertical plane in a clockwise (θ; positive) as well as in a counter-clockwise (ϕ; negative) direction as illustrated with the dotted lines. The output was observed at 0, 10, 20 and 30^{o} angle of tilt in both directions (Table 2). The theoretical distance sensed by the transducer at any angle of tilt could be estimated as follows:



Note:

ϕ = Assumed as the negative angle and

θ = As the positive angle

Figure 7. The schematic diagram for the angle of tilt.

$$L = 35/\cos\theta$$

where: L is the theoretical distance sensed by the transducer and θ angle of tilt.

The equivalent depth of tillage from the calculated (theoretical) distance (L) could be found as 45 cm minus the calculated distance (L). Thus, the output voltages could be determined from Figure 10 for a given value of tillage depth (Table 2) in order to compare it with the observed values.

4.5 Arrangement for Noise Test

Tillage implements are operated by tractors which create a noise level of 75-100 dBA. Since the depth sensor is a device which utilizes sound pulses to activate the circuitry, it was necessary to test it for the possibility of tractor noise interference. For this purpose a tractor (Massey Ferguson 150; 35 HP) was operated adjacent to the depth sensor. The noise (87-92 dBA) was produced by accelerating and de-accelerating the tractor and the output of the depth sensor was recorded in this condition which was compared with the output of zero noise condition.

4.6 Arrangement for Stubble Test

The stubble test was also conducted under simulated field conditions, stems of wheat stubble were planted in the soil bin bed on the plot area of 200 cm x 60 cm (Figure 8). The plot was orientated in such a way that the long axis matched

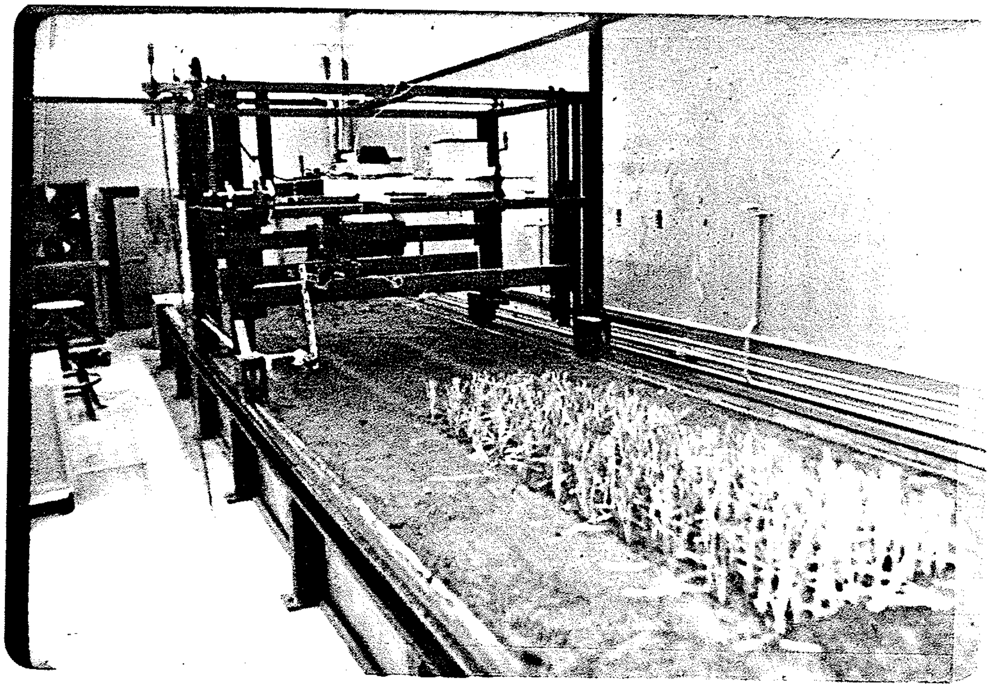


Figure 8. The simulated stubble arrangement on the soil bin.

the direction of travel and the rows of stubble ran perpendicular. The row spacing was 10 cm while the plant to plant spacing in rows was 6 cm. The plants were arranged in a staggered fashion from row to row and provided a stubble population of 67×10^5 tillers/ha (17×10^5 plants/ha) since four tillers were assumed per plant on an average basis. The height of the stubble was 17 cm.

4.7 Dynamic Response and Simulated Test

The depth sensor is intended to indicate the equivalent depth reading in the form of an analog signal, thus it is significant to evaluate the dynamic response of this signal in the simulated field conditions. The soil bin was utilized for this experimentation to simulate a rough field surface condition by placing wooden blocks of various sizes on its bed (Figure 9).

To simulate the depth of tillage, wooden blocks of various lengths and heights (Table 1) were arranged in the middle of the soil bin such that the transducer mounted (at 45 cm height i.e. zero depth of tillage) could sense their heights. The height of the wooden blocks represented the depth of tillage. The wooden surface will not affect the output in comparison to the soil surface (section 5.1).

Arrangements of wooden blocks for various speeds of travel, block lengths and heights are illustrated in Table 1. It is explained above that the height of blocks was simulated to

Table 1. Wooden Block Arrangements on the Soil Bin for the Simulated Tests*

S.No.	Set	Wooden blocks Height (cm)	Wooden blocks Length (cm)	Speed of travel (km/h)
	A	varying speed		
1.		4.9	488	2.4
2.		"	"	3.1
3.		"	"	3.4
4.		"	"	3.9
	B	varying block length		
1.		4.6	244	2.1
2.		"	310	2.1
3.		"	386	2.1
	C	varying block length		
1.		9.2	380	2.1
2.		"	446	2.1
3.		"	460	2.1

*Length of the blocks was arranged along the direction of travel and height simulated the depth of tillage while the width was 1 m.

the depth of tillage while their length was arranged along the direction of the soil bin travel. Arrangements in Table 1 are divided into set A, B and C for ease of study. Set A was meant for examining the signal response at 2.4, 3.1, 3.4 and 3.9 km/h for a 4.9 cm sudden change in the depth over a 488 cm length, while set B and C were meant to compare the response for varying length of blocks at the simulated depth of 4.9 cm and 9.2 cm, at a constant speed of 2.1 km/h. Arrangement of set A; S. No. 1 of this table was fashioned to predict the signal delay. To accomplish this the second pen of the recorder actuated by a microswitch positioned on the soil bin carriage that located the block in respect to the transducer, was used to mark on the chart.

In an additional wooden block arrangement which was set up to examine the output of the depth sensor for small variations in the field at 2.1 km/h blocks (100 cm x 8.6 cm x 4 cm) were arranged at 1 m OC intervals in such a way that their width (8.6 cm) was along the travel direction and the height (4 cm) simulated depth of tillage (Figure 9).

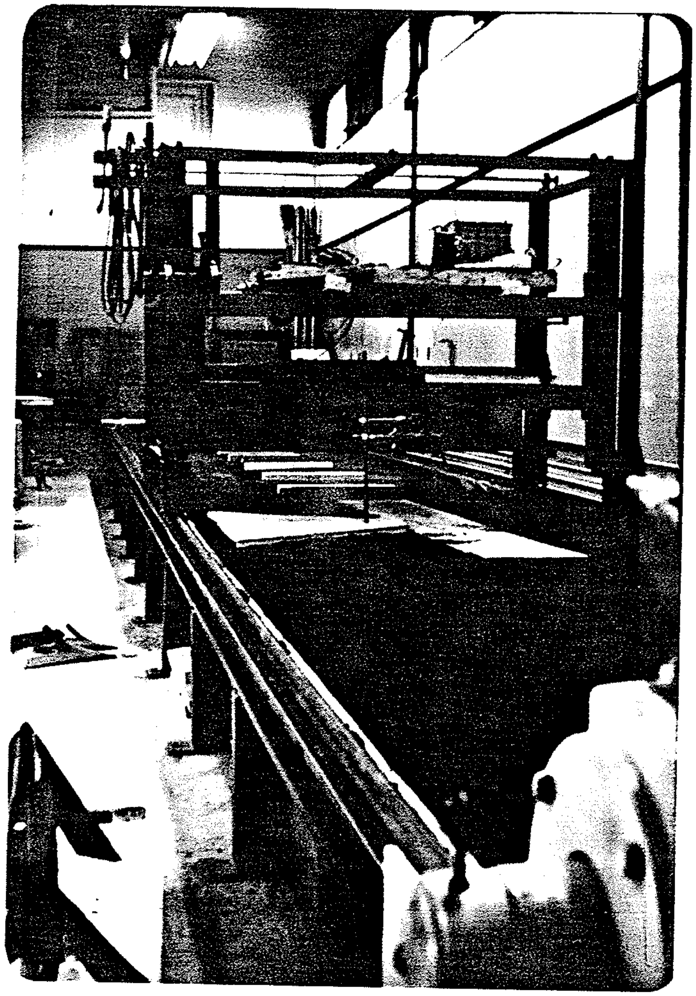


Figure 9. The wooden block arrangement on the soil bin (here blocks are shown only on the half length of the soil bin but in experiments the full length was utilized).

CHAPTER V

RESULTS AND DISCUSSION

5.1 Calibration of the Depth Sensor

The depth sensor calibration on plywood panel, steel plate, water, sandy loam, Red River clay and peat soil showed a linear relationship between the output voltage and the depth of tillage operation (Figures A.2.1 to A.2.7). Figure 10 shows a best fit straight line obtained by pooling all the data from Table 2 on the above mentioned surfaces. All the best fit straight lines obtained for the above surfaces showed a coincidence with each other since the respective slopes and intercepts of the lines were similar (Kleinbaum and Kupper 1978), thus it can be concluded that the surfaces have no appreciable effect on the output of the depth sensor and may be pooled. With a linearity of ±1.8% considered on the full scale depth of 17 cm the accuracy is found to be ±3 mm.

Figure 10 will be utilized to compare the results of various tests in the upcoming sections. Results obtained on the recorder chart paper (Figure 11 to 18) will be compared by scaling the output in terms of the depth of tillage. The basis of scaling is as follows:

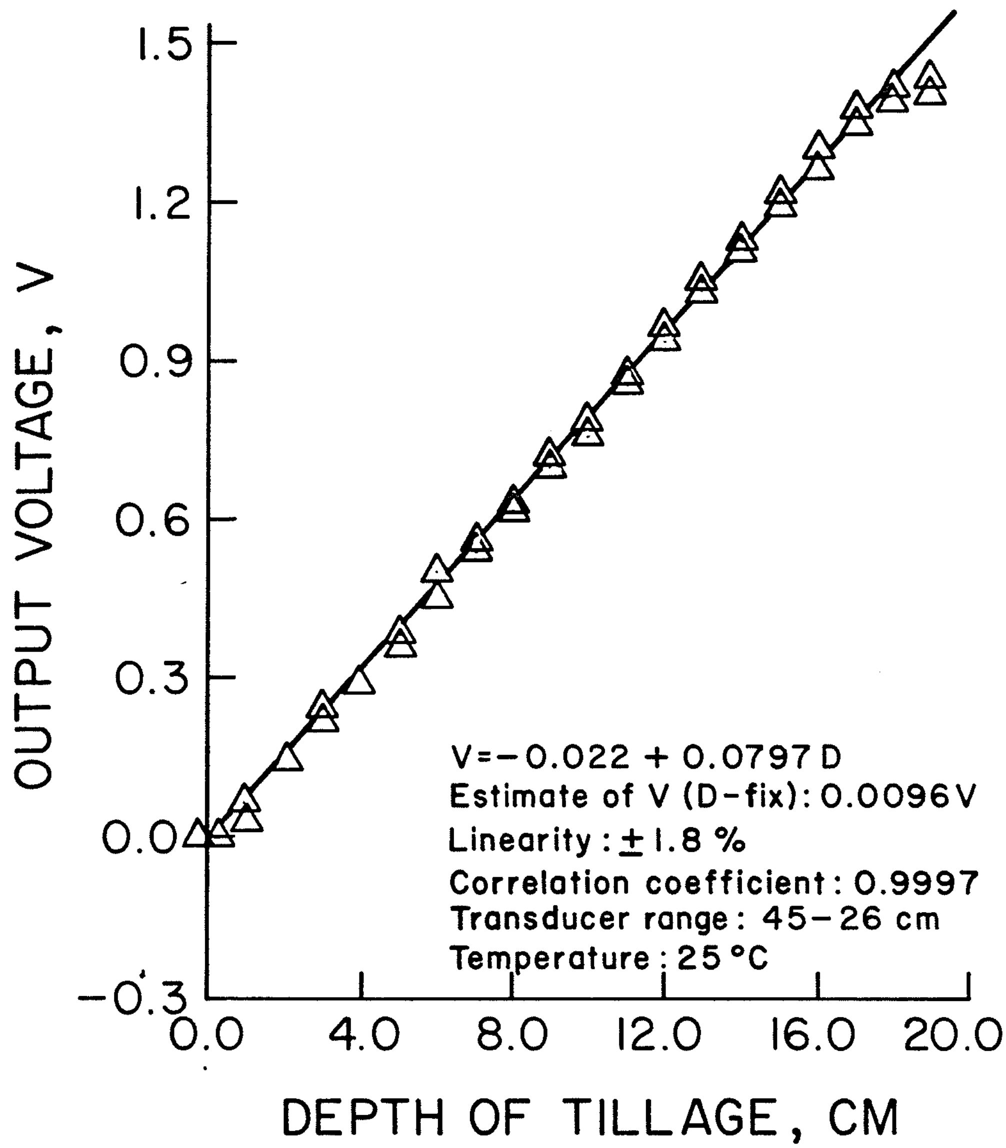


Figure 10. Calibration curve for the pooled data set which includes all surfaces. Points beyond 17 cm are excluded from the equation.

Table 2. The Output Voltage versus the depth of Tillage (D) by Using Plywood, Steel, Water, Sandy Loam, Clay and Peat Soil Under the Transducer.

Temperature: 25^{o}C
Transducer Range: 45-26 cm

Depth of Tillage (cm)	Output Voltage (V)													
	Plywood		Steel		Water		Sandy Loam m.c.=1%		Red River Clay m.c.=8.35%		Red River Clay m.c.=50.2%		Peat Soil m.c.=253.3%	
	VID*	VDD+	VID	VDD	VID	VDD	VID	VDD	VID	VDD	VID	VDD	VID	VDD
0.0	-0.02	-0.02	-0.02	-0.01	-0.01	0.00	-0.03	-0.02	-0.03	-0.02	-0.01	+0.00	-0.03	-0.02
1.0	0.05	0.05	0.06	0.07	0.07	0.06	0.04	0.06	0.05	0.06	0.07	0.06	0.05	0.05
2.0	0.14	0.14	0.15	0.15	0.15	0.15	0.15	0.15	0.14	0.13	0.15	0.15	0.14	0.14
3.0	0.20	0.21	0.22	0.22	0.22	0.23	0.22	0.22	0.21	0.21	0.21	0.23	0.21	0.21
4.0	0.29	0.29	0.30	0.30	0.28	0.29	0.29	0.30	0.29	0.30	0.28	0.29	0.29	0.29
5.0	0.36	0.36	0.37	0.38	0.37	0.38	0.38	0.38	0.36	0.37	0.37	0.38	0.38	0.38
6.0	0.44	0.45	0.46	0.46	0.45	0.46	0.47	0.46	0.46	0.46	0.45	0.46	0.45	0.48
7.0	0.53	0.53	0.54	0.54	0.54	0.54	0.54	0.53	0.53	0.53	0.54	0.54	0.52	0.53
8.0	0.61	0.60	0.62	0.62	0.60	0.62	0.62	0.62	0.61	0.60	0.60	0.62	0.60	0.60
9.0	0.70	0.69	0.70	0.70	0.69	0.70	0.70	0.71	0.69	0.69	0.69	0.70	0.69	0.69
10.0	0.75	0.77	0.78	0.78	0.76	0.77	0.77	0.79	0.76	0.77	0.76	0.77	0.77	0.77
11.0	0.84	0.84	0.85	0.86	0.84	0.85	0.84	0.86	0.84	0.85	0.84	0.85	0.87	0.85
12.0	0.92	0.92	0.94	0.94	0.92	0.94	0.94	0.94	0.92	0.92	0.92	0.94	0.92	0.92
13.0	1.01	1.01	1.03	1.02	1.00	1.01	1.02	1.01	1.02	1.01	1.00	1.01	1.01	1.00
14.0	1.08	1.09	1.11	1.10	1.08	1.10	1.10	1.10	1.11	1.11	1.08	1.10	1.10	1.10
15.0	1.18	1.18	1.18	1.19	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18
16.0	1.25	1.26	1.26	1.27	1.26	1.26	1.26	1.27	1.27	1.26	1.26	1.26	1.26	1.25
17.0	1.31	1.32	1.32	1.32	1.32	1.35	1.32	1.33	1.33	1.33	1.32	1.35	1.34	1.34
18.0	1.37	1.36	1.37	1.37	1.36	1.36	1.37	1.37	1.36	1.36	1.36	1.36	1.39	1.37
19.0	1.37	1.37	1.37	1.37	1.37	1.37	1.37	1.37	1.37	1.37	1.37	1.37	1.40	1.40

*VID = output voltage for increasing depth of tillage.
+VDD = output voltage for decreasing depth of tillage.

$$\text{depth of tillage (cm)} = \frac{3V}{25cm} \times \frac{19\ cm}{1.46\ V} \times Y\ cm$$

where:

$\frac{25\ cm}{3\ V}$ = Recorder sensitivity

19 = Full scale depth of tillage (cm) from Figure 10

1.46 = Full scale predicted output (V) from Figure 10

Y = Vertical divisions on the chart paper from the output of zero depth of tillage (cm)

5.2 Dust Test

The dusty condition which was simulated to represent a severe dusty field condition as explained in section 4.3 did not indicate any interference on the depth sensor output as shown in Figure 11. It is the opinion of the author that dust conditions in the field would never be more severe than that created by the simulated test.

5.3 Transducer Tilting Test

Table 3 illustrates observed and calculated values of the output voltage for the transducer angle of tilt -30 to 30^{o} (for more details see section 4.4). Observed and calculated voltage values are close for a given angle of tilt, thus the observed output at any angle of tilt is equivalent to the depth of tillage sensed by the depth sensor. The observed output

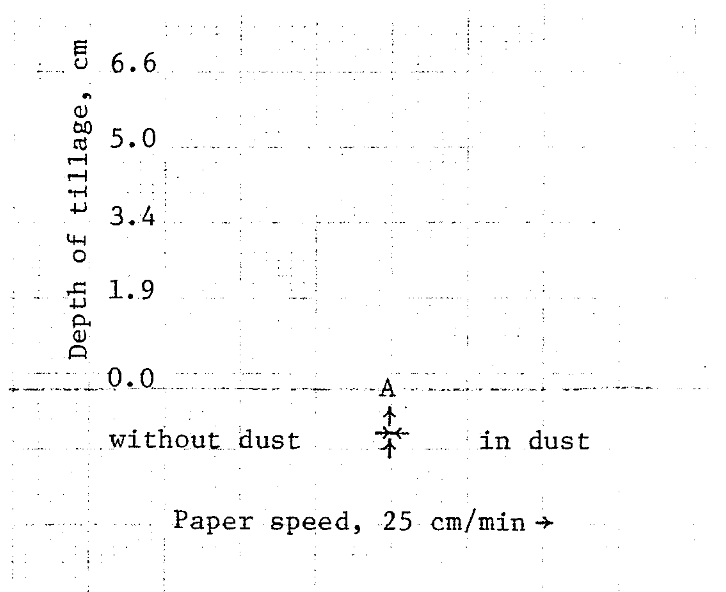


Figure 11. The effect of dust on the performance of the depth sensor when stationary (sensitivity 1.562 cm depth of tillage = 1 cm of chart).

Table 3. Observed Voltage (V_o) and Calculated Distance (L), Simulated Depth of Tillage* (D) and Equivalent Output (V_c) for the Transducer Angle of Tilt -30 to 30^o from the Vertical

Angle of Tilt (^{o})	Observed Output (V_o)	Calculated Distance, L (cm)	Simulated Depth of Tillage, D (cm)	Calculated Equivalent Output (V_c)
0	0.77	35.0	10.0	0.77
10	0.74	35.5	9.5	0.73
20	0.60	37.2	7.8	0.60
30	0.34	40.4	4.6	0.35
- 0	0.77	35.0	10.0	0.77
-10	0.74	35.5	9.5	0.73
-20	0.59	37.2	7.8	0.60
-30	0.34	40.4	4.6	0.35

*Simulated depth of tillage: (45 - L)cm

voltage was increased by 55% w.r.t. the output at zero angle of tilt when the transducer angle of tilt was 30^{o} (both directions i.e. clockwise and counter-clockwise) but 3.9% at 10^{o} tilt (both directions i.e. clockwise and counter-clockwise) while the accuracy of the depth sensor is 1.8% (section 5.1). It showed that extreme tilting of the transducer will affect the output but any positioning of the unit "by eye" will be well within the 10^{o} tilt and the output will not be appreciably affected.

5.4 Tractor Noise Test

Figure 12 illustrates the output obtained when the depth sensor is subjected to tractor noise (section 4.5). The output up to point A on the chart representing depth monitoring without any noise and beyond A it is with the tractor noise of the level of 87 to 99 dBA. The straight line of the output exhibits that the depth sensor will operate without interference from typical tractor noise.

5.5 Effect of Ground Cover Stubble

It is desirable that the depth sensor would monitor accurately under all operating conditions and it is most significant to determine the effect of stubble on its output. To examine this, the output was recorded in the simulated stubble test as explained in section 4.6. Figure 13 illustrates the recorded output of the depth sensor operating over a 200 cm long patch of stubble in the soil bin at a speed of 2.1 km/h.

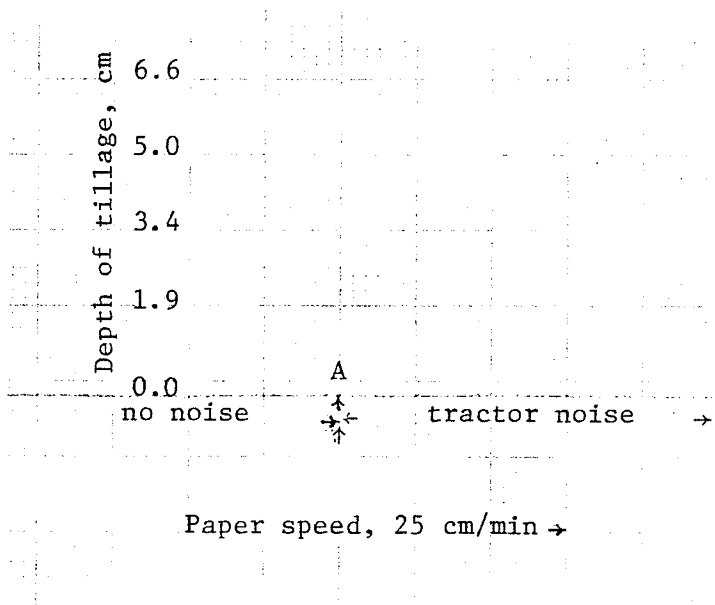


Figure 12. The effect of tractor noise (87 to 92 dBA) on the performance of the depth sensor (sensitivity 1.562 cm depth of tillage = 1 cm of chart).

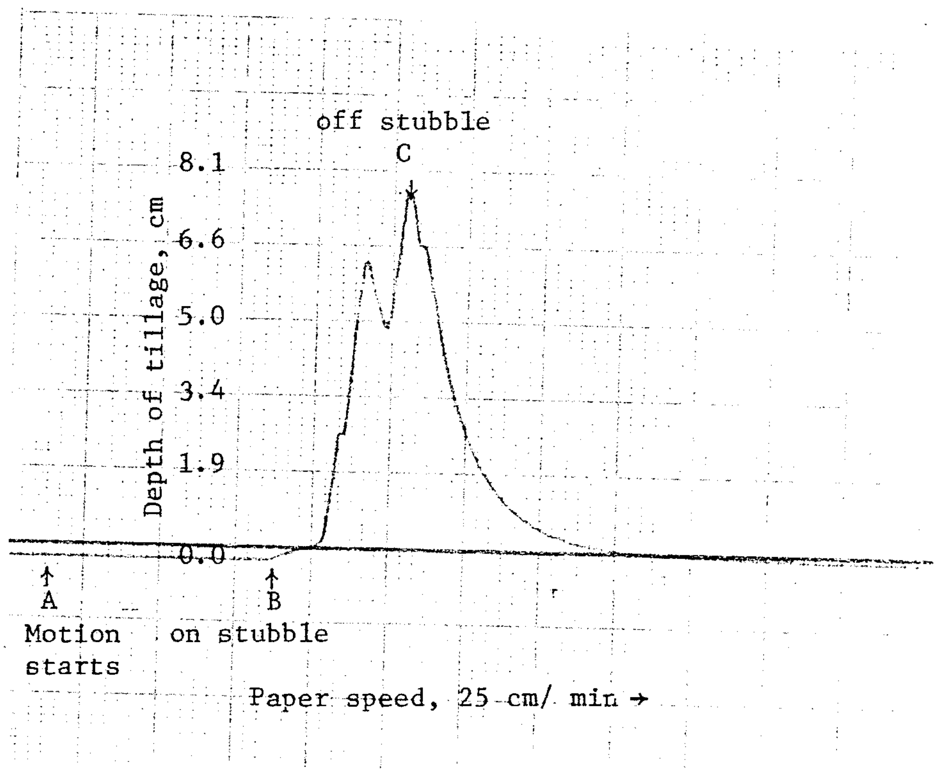


Figure 13. The effect of stubble on the performance of the depth sensor when traveling at 2.1 km/h (sensitivity 1.562 cm depth of tillage = 1 cm of chart).

The figure shows that the output from A to B for zero depth of tillage was a straight line but as the transducer passed over the stubble it increased from B to C and again returned back (slowly due to damping) to the original position for zero depth of tillage.

From the above results it can be concluded that stubble had an appreciable effect on the output of the depth sensor. The effect in the above test is similar to as it could have been with another surface (solid) of 7.7 cm height under the transducer but it is not proportional to the stubble height (17 cm). This is because the stubble did not provide a solid surface since it is not thickly populated and at some places (in between the rows) the transducer will sense the ground (zero height of stubble or zero depth of tillage) while at other (on stubble) it will sense the top of the stubble. Thus the output will increase or decrease (or vice versa) and the unit will not be able to indicate a true reading (for more details of the output behaviour, see section 5.6).

5.6 Dynamic Response and Simulated Test

The output response to the change in the depth of tillage was intended to be a slow and delayed response due to the damping action of filters used in the circuitry (Figure 3 and A.1.3). It means that the output should demonstrate an amplitude delay with respect to the input. A set of experiments were conducted to evaluate and establish the behaviour of the output signal. The experimentation procedure is explained in section 4.7.

Figure 14 illustrates the output of the depth sensor on a 4.9 cm high and 488 cm long wooden block at 2.4 km/h speed of the soil bin travel. It had been discussed in section 4.7 that the height of the block was simulated to the depth of tillage operation. The point A in the figure was registered as the transducer coincided with the edge of the block and B when it left the other edge of the block and sensed the ground. The output registered between A and B is on the block surface. It is noted from the figure that the signal was delayed by 0.3 s. The time constant of the depth sensor which is defined as the time to attain 63.2 percent of its maximum output is 1.5 s. Theoretically the time to attain the full stage of the output is described to be infinite but for the purpose of simplicity it may be approximated as 7.2 s from the figure by using the maximum equivalent output* for 4.9 cm (height of the block). Here it will be worthwhile to bring out one more point into focus that is, the time of the depth sensor to travel over the block may be equal to or greater (maximum by 2 x 0.30 s) than the time taken by the output to obtain it's maximum stage (eg. from A' to B', chart of Figure 14) depending on the pattern of the first and the last sound burst striking the block since the sound bursts from the transducer are transmitted

*Output proportional to the block height.

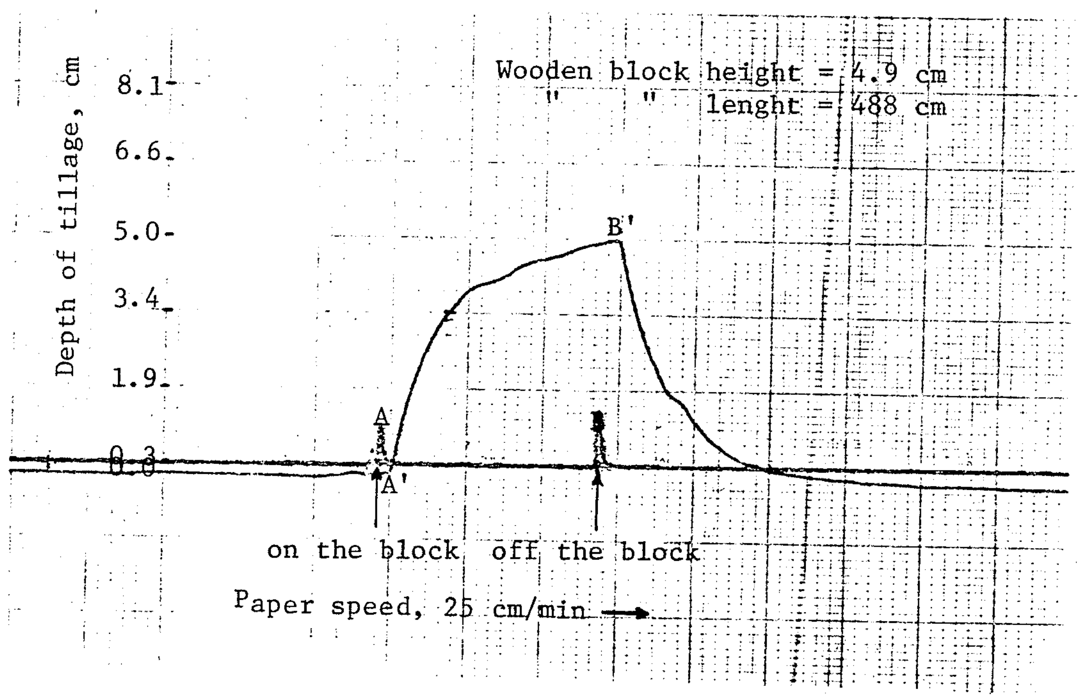


Figure 14. Determination of signal delay time when the depth sensor was traveling at 2.4 km/h. (sensitivity 1.562 cm depth of tillage = 1 cm of chart).

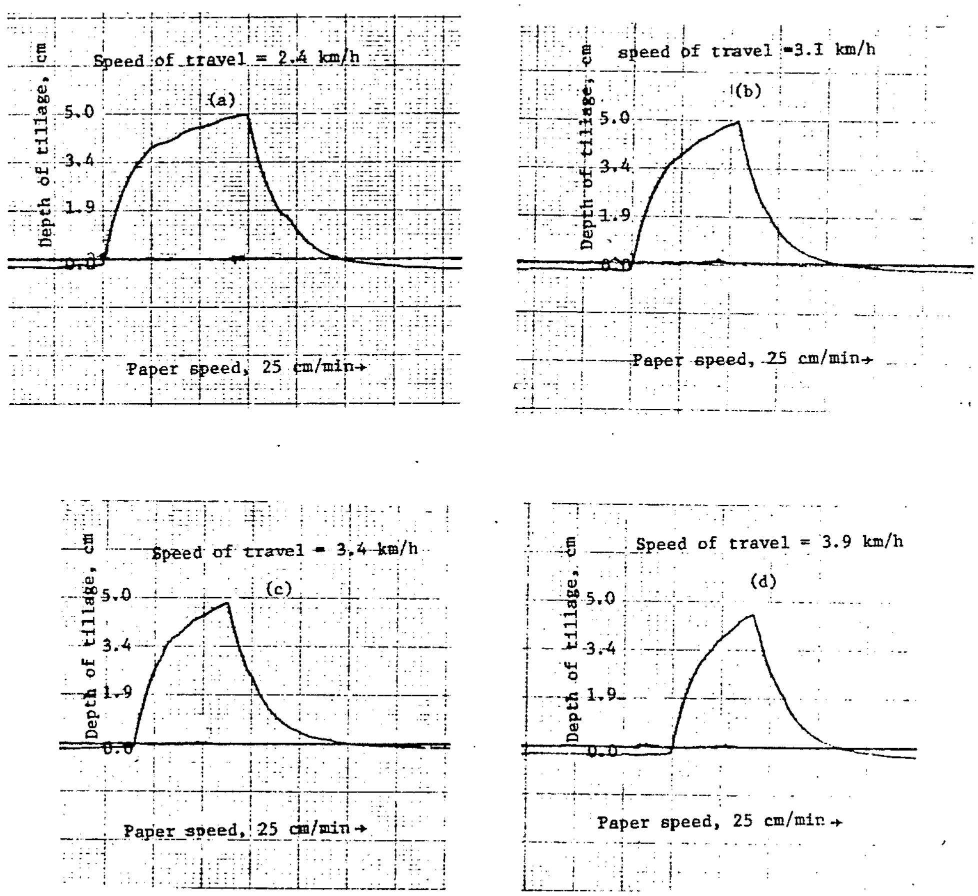
at 0.3 s time interval. In the preceding discussions the time to attain the maximum stage of the output will be taken from the charts irrespective of the time of travel over the block.

Figure 15 illustrates the depth sensor output when the transducer passes over a wooden block 4.9 cm high and 488 cm long at 2.4, 3.1, 3.4 and 3.9 km/h speed of travel respectively. It indicates a maximum of 8.0% decrease in the output with the 62.5% (2.4 to 3.9 km/h) increase in the speed. This phenomenon is somewhat misleading as it could be erroneously assumed that the output is affected by the speed of travel. At 2.4 km/h the output is approximately proportional to the height of the block (4.9 cm) since the time to attain maximum stage of the output is 7.2 s. At a speed of 3.1 km/h or higher the time to attain the maximum stage of the output for a certain depth maintained constant over a length of 488 cm is less than 7.2 s, thus the depth sensor will not show the maximum equivalent output but some percentage of it.

Figure 16 illustrates the output obtained at a speed of 2.1 km/h on a 4.9 cm high block by adjusting its length to 386, 310 and 244 cm respectively (Table 1). The maximum stage of the output obtained in the figure is less than the maximum equivalent output and the same explanation is valid here as discussed previously. Since the maximum time for the depth sensor to attain the maximum stage of the output for 4.9 cm depth of tillage, while travelling over the 386 cm block is 6.0 s (which is less than 7.2 s to attain its maximum equivalent

Wooden block length = 488 cm

Wooden block height = 4.9 cm

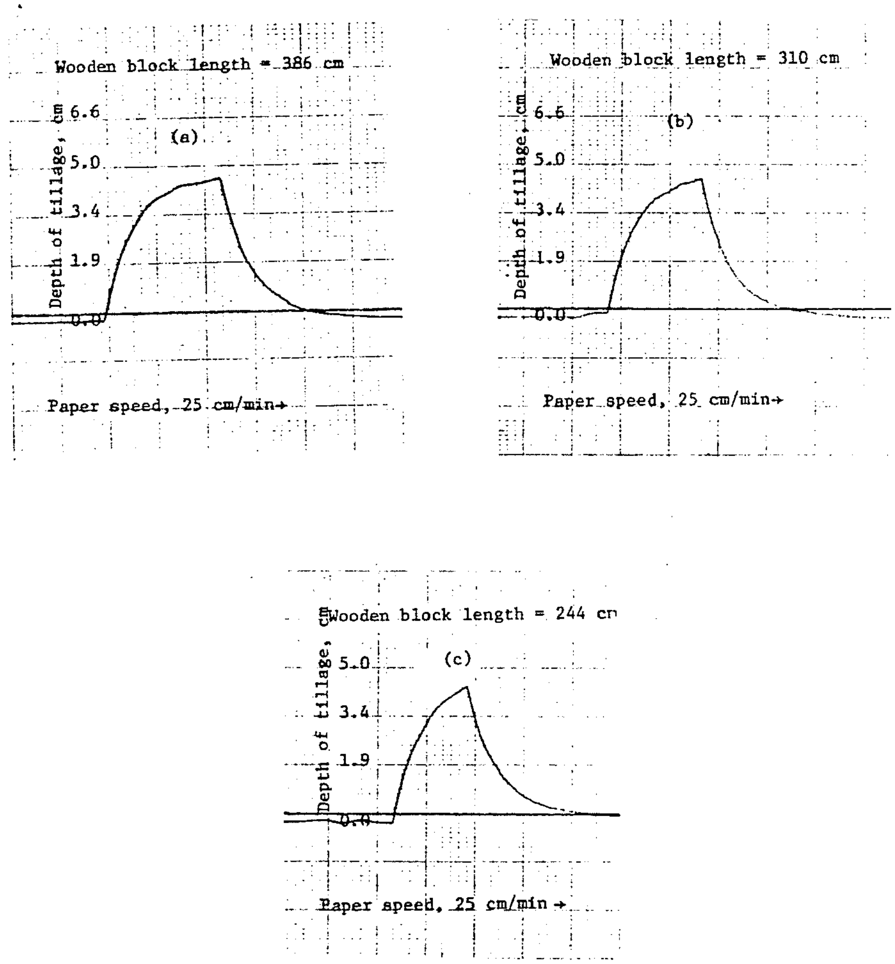


Scale 1:1.6

Figure 15. Determination of the output signal response on a 4.9 cm high and 488 cm long block arranged in the middle of the soil bin when the depth sensor is traveling at (a) 2.4 km/h (b) 3.1 km/h and (c) 3.9 km/h (sensitivity 1.562 cm depth of tillage = 1 cm of chart).

Speed of the depth sensor travel = 2.1 km/h

Wooden block height = 4.9 cm



Scale 1:1.6

Figure 16. Determination of the signal response when the depth sensor is traveling at 2.1 km/h and the block of 4.9 cm height is arranged at three different lengths: (a) 386 cm (b) 310 cm and (c) 244 cm (sensitivity 1.562 cm depth of tillage = 1 cm of chart).

output), thus the depth sensor registered the output but less than the maximum equivalent output for the 4.9 cm high wooden block (depth of tillage). The same story is depicted by the outputs in this figure for 310 and 244 cm blocks.

Figure 17 represents a similar model as that presented in figure 16 except the height of the block is 9.2 cm and lengths of 460 cm, 446 cm and 380 respectively. At 460 cm and 446 cm the time to attain the maximum stage of the output are 7.4 s and 7.2 s which are respectively greater than and equal to 7.2 s (minimum time required to attain the maximum equivalent output). Therefore, the depth sensors registered the outputs which are the true readings (i.e. maximum equivalent output for 9.2 cm depth of tillage) whereas for 380 cm long wooden block the time to attain the maximum stage of the output is 5.8 s and hence the output (i.e. for 8.7 cm depth of tillage) registered is less than the maximum equivalent output for 9.2 cm high block. Figures 15 and 17 illustrated that the time of attaining the maximum stage of the output affects the output of the depth sensor irrespective of the depth of tillage.

Figure 18 is the output for blocks (100 cm x 8.6 cm x 4 cm) arranged at a spacing of 1 m. Their 8.6 cm dimension was placed in line with the direction of travel and the height simulated to the depth of tillage. The output as shown in Figure 18 is jagged and approximately equivalent to 1 cm depth of tillage. Here the time for the depth sensor to attain the maximum output is 0.4 s which is very small in comparison to

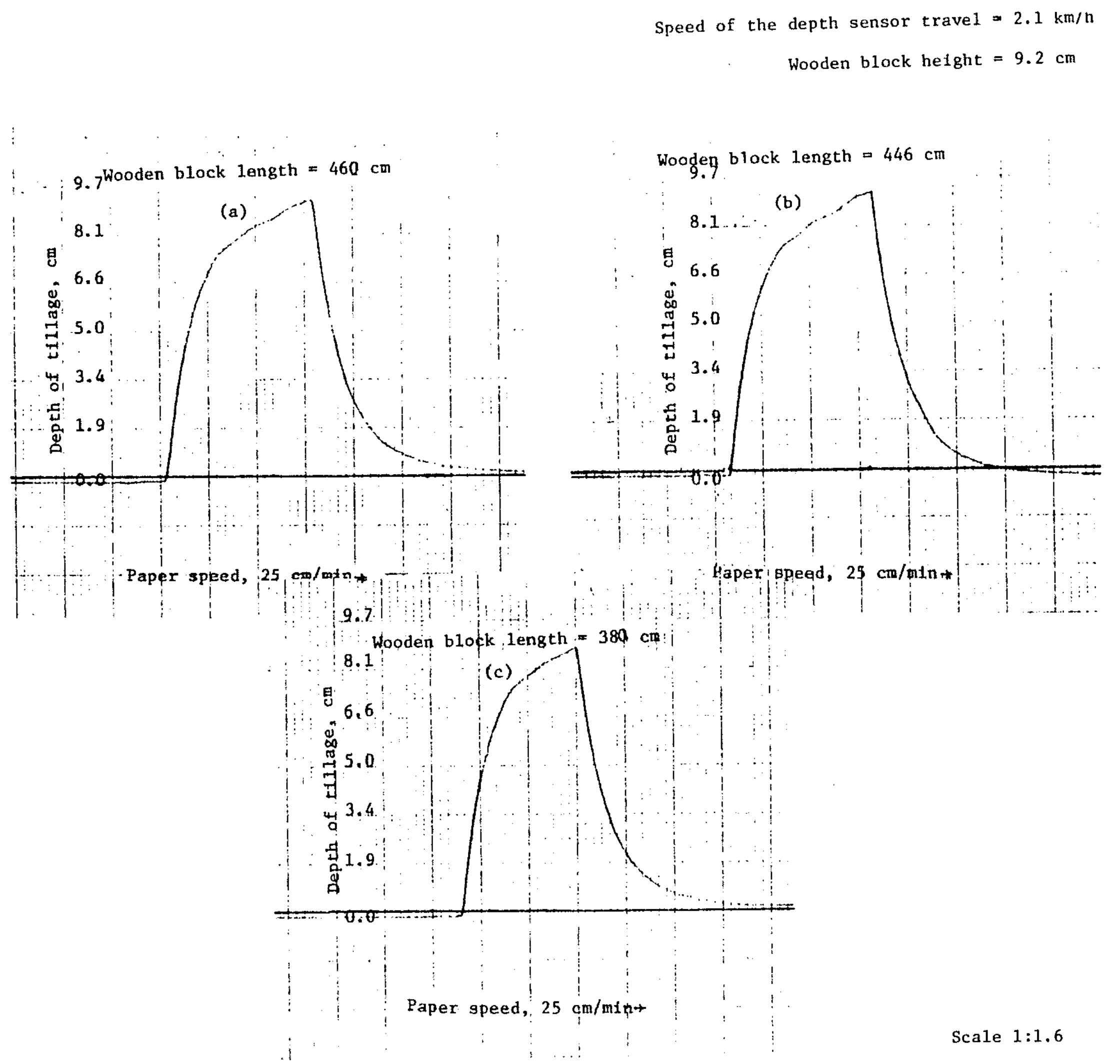


Figure 17. Determination of the output signal response when the depth sensor is traveling at 2.1 km/h and the block of 9.2 cm height is arranged in the middle of the soil bin at three different lengths: (a) 460 cm (b) 446 cm and (c) 380 cm (sensitivity 1.562 cm depth of tillage = 1 cm of chart).

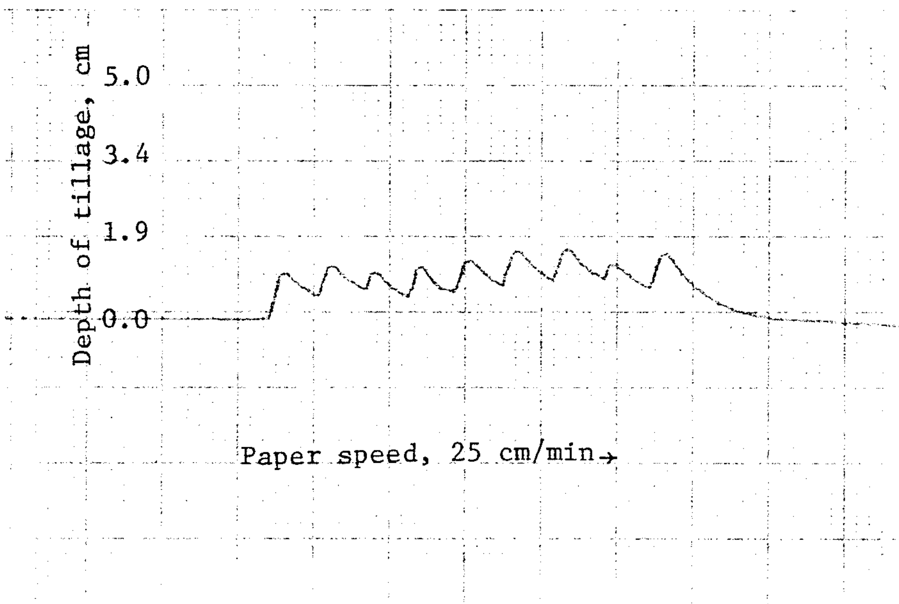


Figure 18. Determination of the output signal response on 8.6 cm wide and 4.6 cm high (simulated depth of tillage) wooden blocks arranged in series at 1 m interval when the depth sensor is traveling at 2.1 km/h (sensitivity 1.562 cm depth of tillage = 1 cm of chart).

7.2 s (minimum time required to attain the stage of the maximum equivalent output) which explains why the output is much less than the equivalent output. It is an advantageous characteristic of the depth sensor to have this response lag since it will eliminate the severe fluctuations of the output.

CHAPTER VI

CONCLUSIONS

The depth sensor developed was found to be practical for tillage implements under most operating conditions. The output was unchanged when subjected to dust, tractor noise, and high speed conditions. The only exception determined in this study was the effect of standing stubble cover on the soil. Preliminary tests showed that this effect was appreciably reduced by monitoring the sensor over the tractor wheel track. The depth sensor was easy to mount on tillage implements without any complicated linkage. All components of the depth sensor were easily available.

The calibration of the depth sensor showed that the output had a linear relationship with the depth of tillage for various surface materials. The best fit line obtained on the mentioned surfaces showed a coincidence with each other predicting no effect of the surfaces on the output. With a linearity of ±1.8% considered on the full scale depth of 17 cm the accuracy was found to be ±3 mm. It was also determined that the time constant of the depth sensor was 1.5 s and it responded slowly to the change in the depth of tillage due to wheel sinking or non-uniform field conditions avoiding the severe fluctuations of the output.

CHAPTER VII

RECOMMENDATIONS FOR FUTURE STUDY

1. To give a compact structure, the digital circuit board should be eliminated and another circuit should be constructed putting in only the necessary components.

2. The calculation for the temperature effect in section 3.6 indicated the possibility of 3.6% inaccuracy in the output for a $\pm 20^{o}C$ variation in the temperature. In any field condition the temperature variation may not be this large although small temperature variations will produce some inaccuracy in the output. To get more accurate results under variable temperature conditions a temperature compensating device could be added. There are various methods that could be considered for temperature compensation but three are suggested here:

   (a) A small target can be used as a reference at a known distance in the ranging path of another transducer and echos of both the transducers could be processed. One distance should be normalized with respect to the other, since the distance to time ratio for each sound burst is the same.

(b) A temperature sensing integrated circuit can be incorporated to derive a VCO (voltage control oscillator) to compensate the timing.

(c) The third method can be employed by using a thermocouple. One junction of the thermocouple can be covered with a wet pad and expose both junctions in the air. The differential temperature at the junctions will produce a temperature dependent current flow in the thermocouple which can be used to control the output of an amplifier w.r.t. the environmental temperature.

LIST OF REFERENCES

ANDERSON, D.T. 1965. Some factors affecting trash conserva- with heavy duty cultivator. Can. Agric. Eng., 6(1): 11-19.

ANDERSON, D.T. 1964. Some factors affecting trash conservation with disc type tillage implements. Can. Agric. Eng., 7(1): 45-49.

COWELL, P.A. and S.C. LEN. 1967. Field performance of tractor draught system. J. Agric. Eng. Res., 12(3): 205-221.

DYCK, F.B. 1975. Automatic depth control for discer. Can. Agric. Eng., 17(1): 47-49.

FENSTER, C.R. 1960. Stubble multching with various type of machinery. Soil Science Society of Amer. proceedings, vol. 24, 518-523.

DRANSFIELD, P., S.T. WILLATT and A.H. WILLIS. 1964. Soil to implement reaction experienced with simple tines at various angles of attach. J. Agric. Eng. Res., 9(1): 220-224.

GABRILIDES, S.TH. 1962. Apparatus for the continuous measurement of the depth of plowing. J. Agric. Eng. Res., 7(2): 202-203.

HARRISON, H.P. 1968. Methods of determining capacity of farm machinery. Trans. ASAE, 11(3): 318-319.

HOLMAN, J.P. and W.J. GAJDA, Jr. 1978. Experimental methods for Engineers, third edition, McGraw-Hill Book Company, New York, New York, U.S.A.

HOOK, R.W. and K.E. MURPHY. 1970. Providing depth control for integral flexible implements. Agricultural Engineering, 51(10): 560-563.

HOOK, R.W. 1968. Hydraulic depth control of multi-section machinery. Agricultural Engineering, 49(12): 732-733.

JEANNOTTE, J. 1971. Rubber tired wheel; adjustable depth control units for flexible ga ged disc blade implements. Canadian Patent No. 913445.

KILCHER, M.R. and T. LAWRENCE. 1970. Emergence of Altai wild rye grass and other grasses as influenced by depth of seeding and soil type. Can. J. of Plant Science, Vol. 5, 475-479.

KLEINBAUM, DAVID G. and L.L. KUPPER. 1978. Applied regression analysis and other multivariable methods, Wodsworth Publishing Company Inc., Belmont, California, U.S.A.

LARTER, E.N. and J. WHITEHOUSE. 1955. Report on barley cultural study. Crop Science Department, University of Saskatchewan, Saskatoon, Canada.

MCLAUGHLIN, N.B., F.W. BIGSY, J.N. WILSON and G.C. ZOERB. 1976. A fluidic transducer for a tillage depth control system. Can. Agric. Eng., 18(2): 10-13.

PAULSON, G.E. and W.P. STRELIOFF. 1974. An ultrasonic depth sensor. Presented in IFAC Symposium, Saskatoon, Saskatchewan, Canada, June 18-20; 1974.

LAL, R. and H. STEPPUHN. 1979. Fall tillage on the Canadian prairies: is it needed? ASAE Paper No. 79-2137.

SMALL, D. 1978. Designing an automatic depth control for commercial onion harvester, presented at 1978 annual meeting of Canadian Society of Agricultural Engineering, Paper No. 78-321.

SMITH, L.A., G.L. BARKER and R.F. COLWICK. 1981. Instrumentation used to monitor energy requirements for agricultural field operations. ASAE Paper No. 81-1043.

SWEET, R. and F.B. DYCK. 1969. Automatic depth control units, Canadian Patent No. 930233.

WENDTE, R.W. and H. ROZEBOOM. 1981. Data acquisition for tillage energy evaluation. ASAE Paper No. 81-1045.

WINSTANLEY, J.W. 1952. Textbook on Sound. Longmans Green and Co., London.

ZOERB, G.C. and G.E. PAULSON. 1977. Developments in automatic controls for agricultural equipments. Presented at the 1977 Annual meeting of American Society of Agricultural Engineering, Brookings, South Dakota.

APPENDIX A

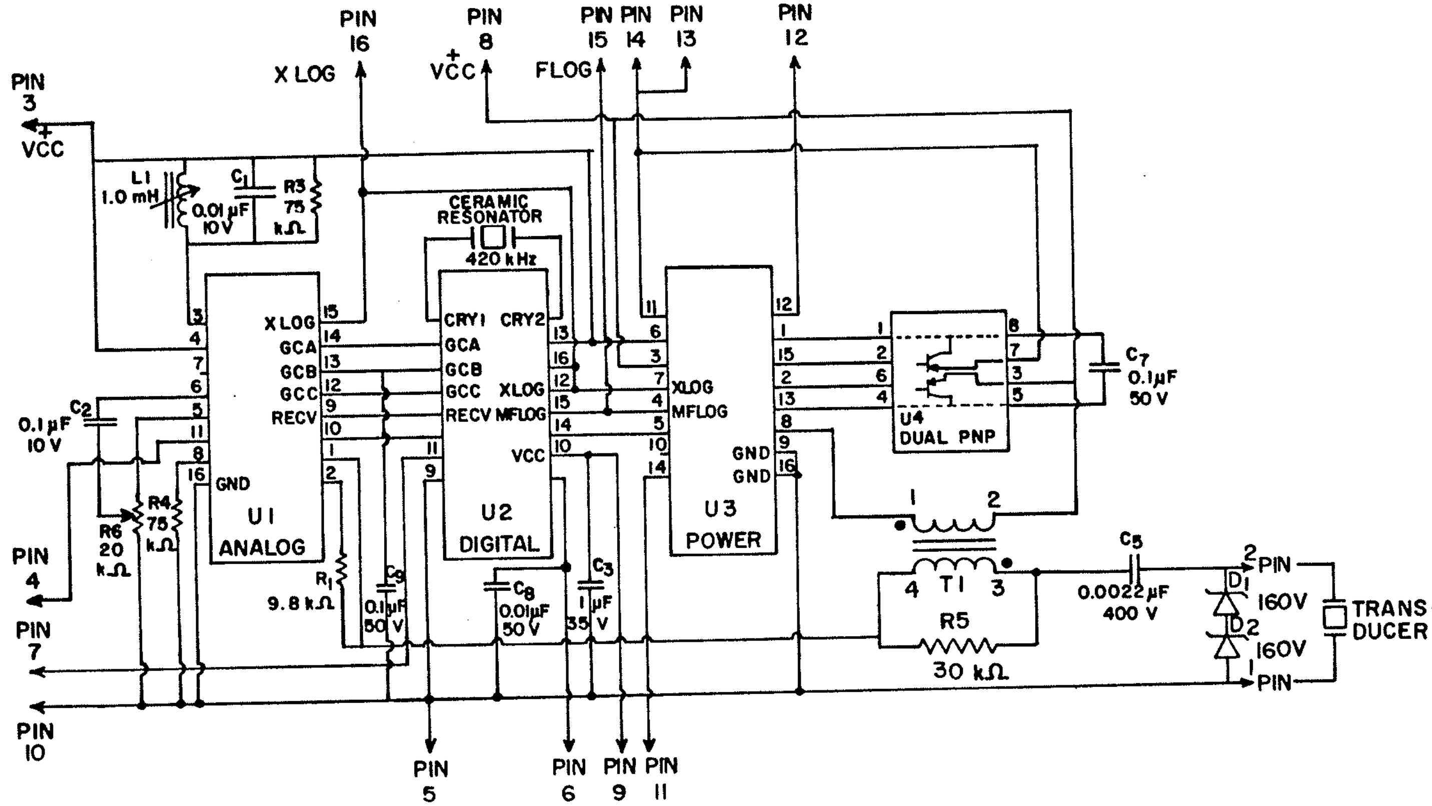


Figure A.1.1. The circuit diagram of the ultrasonic ranging unit circuit board (courtesy of the Polaroid Corp.).

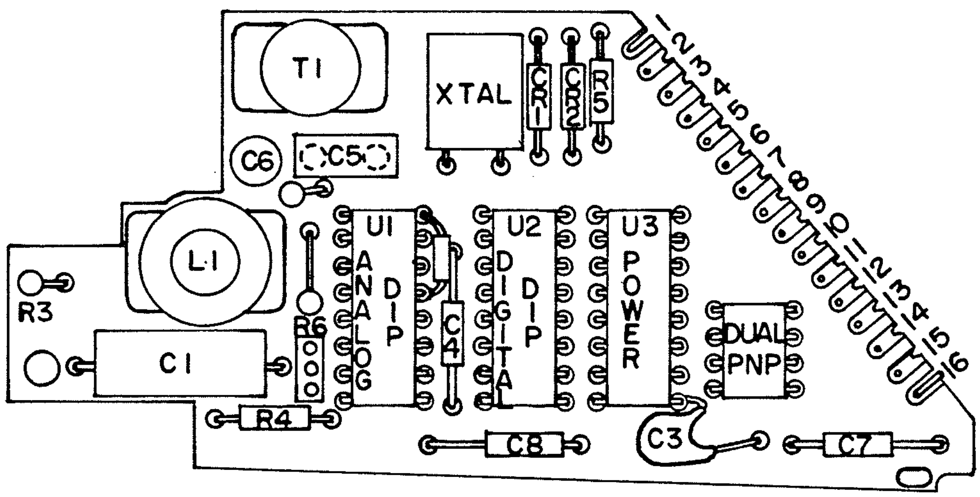
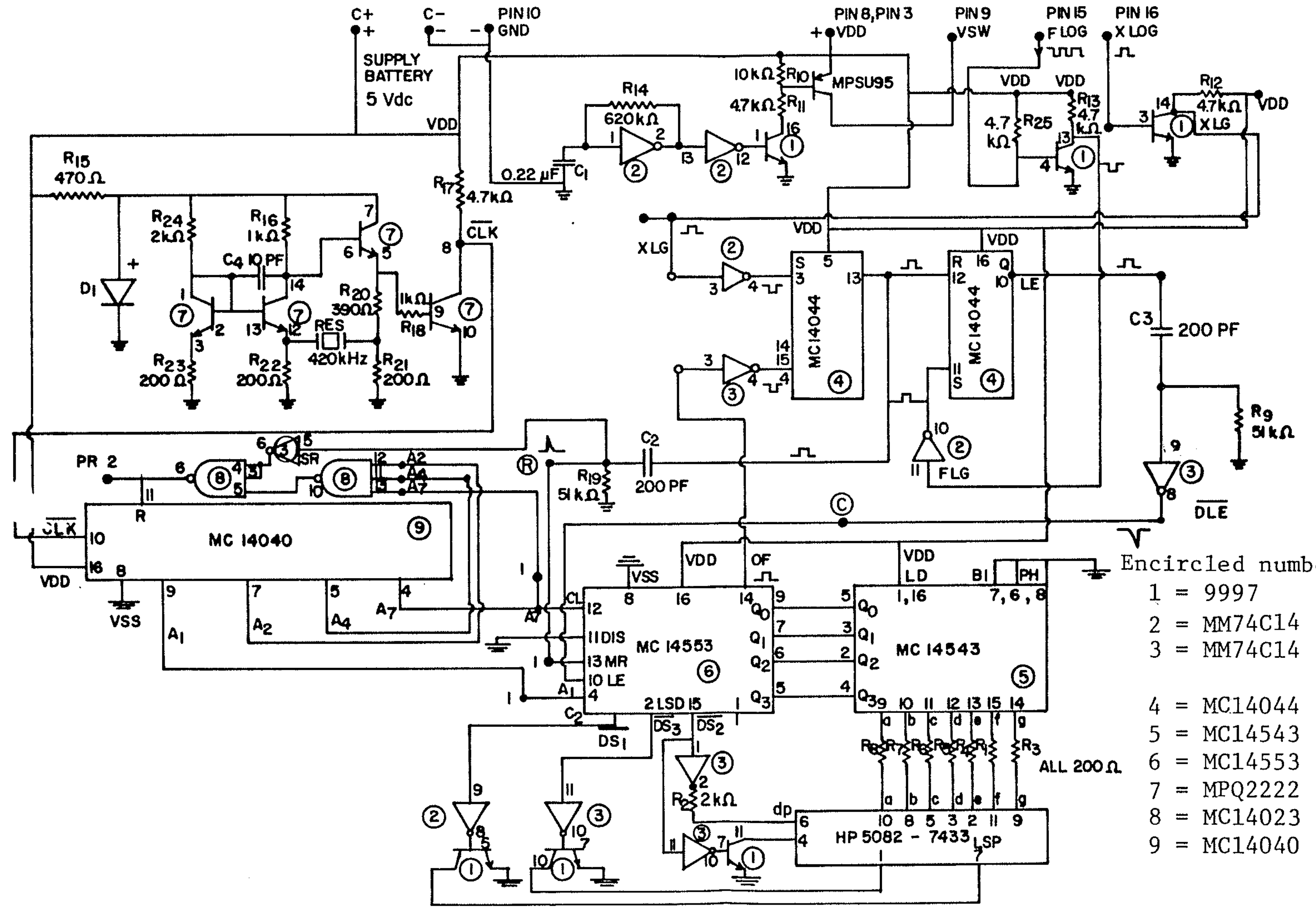


Figure A.1.2. Component layout of the ultrasonic ranging unit circuit board (courtesy of the Polaroid Corp.).



Encircled numbers
1 = 9997
2 = MM74C14
3 = MM74C14 (middle in Figure A.1.4)
4 = MC14044
5 = MC14543
6 = MC14553
7 = MPQ2222
8 = MC14023
9 = MC14040

Figure A.1.3. The circuit of the digital circuit board (courtesy of the Polaroid Corp.).

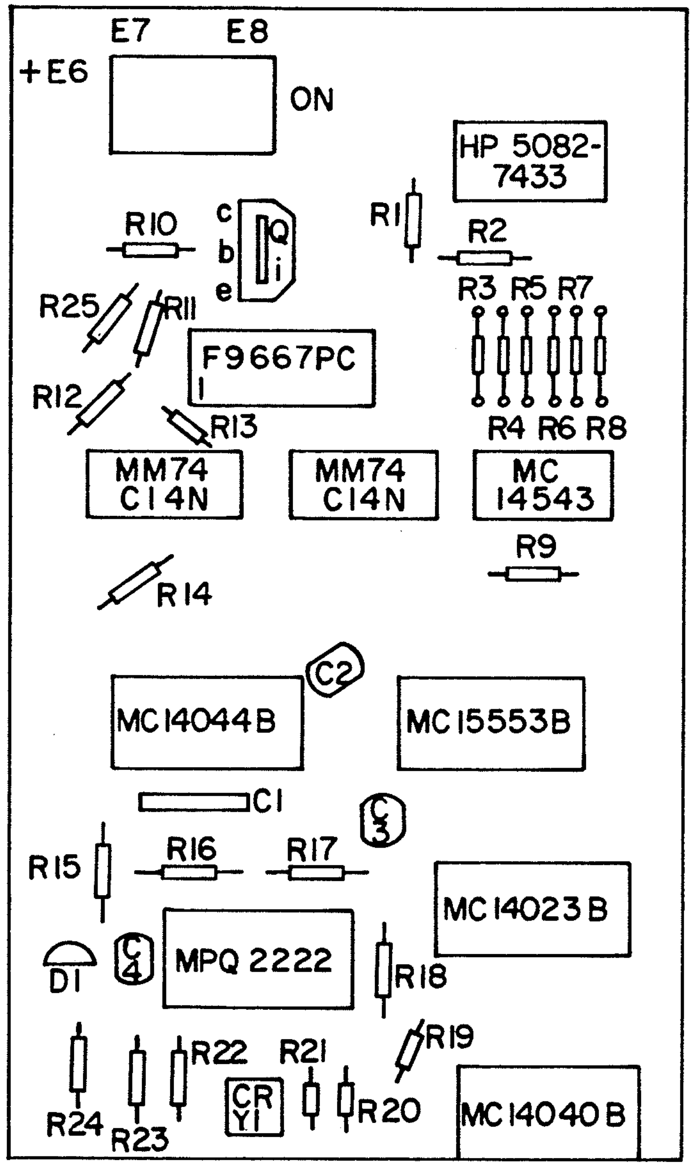


Figure A.1.4. Component layout of the digital circuit board

(courtesy of the Polaroid corp.).

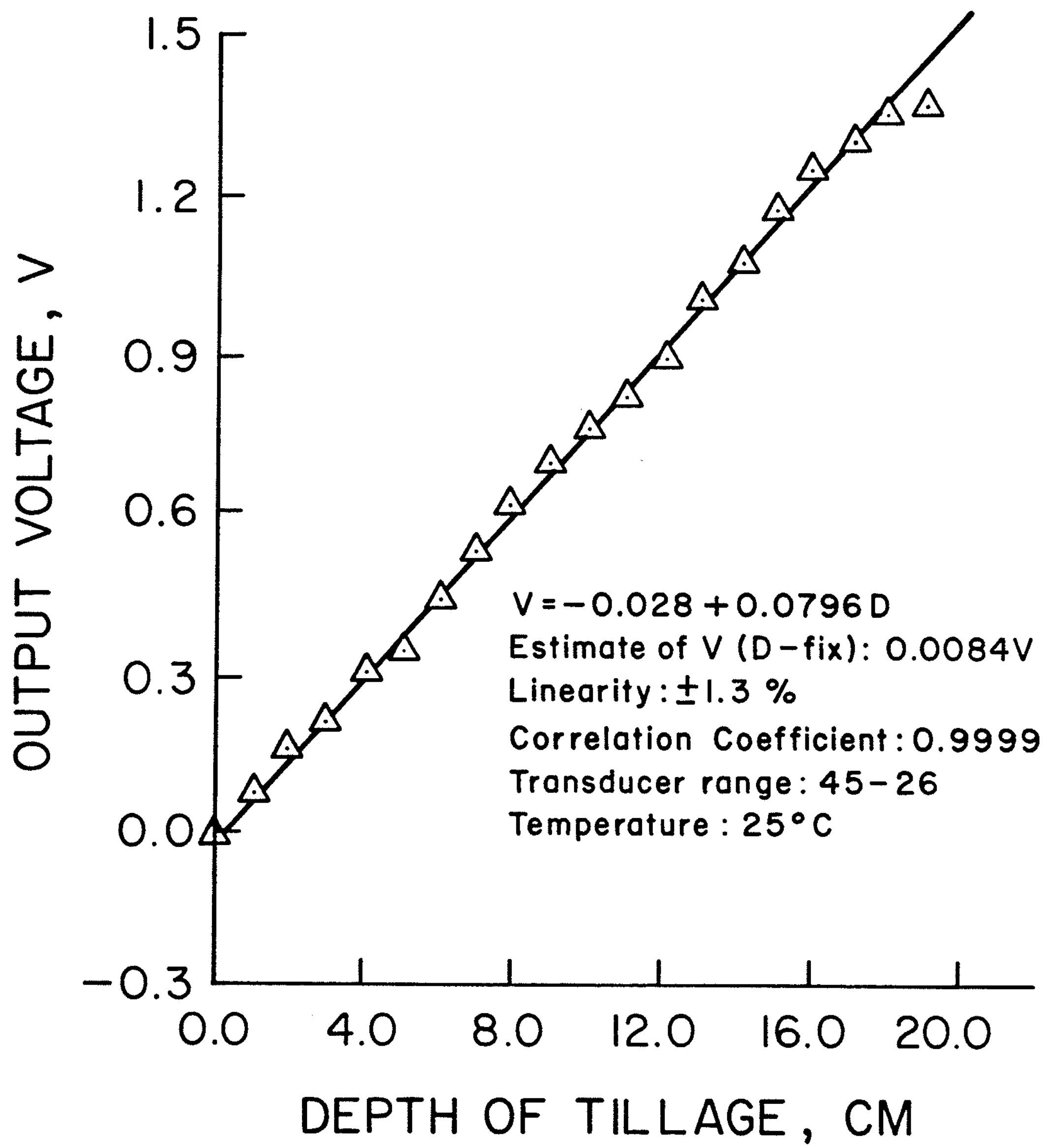


Figure A.2.1. Calibration curve for the plywood surface. Points beyond 17 cm are excluded from the equation.

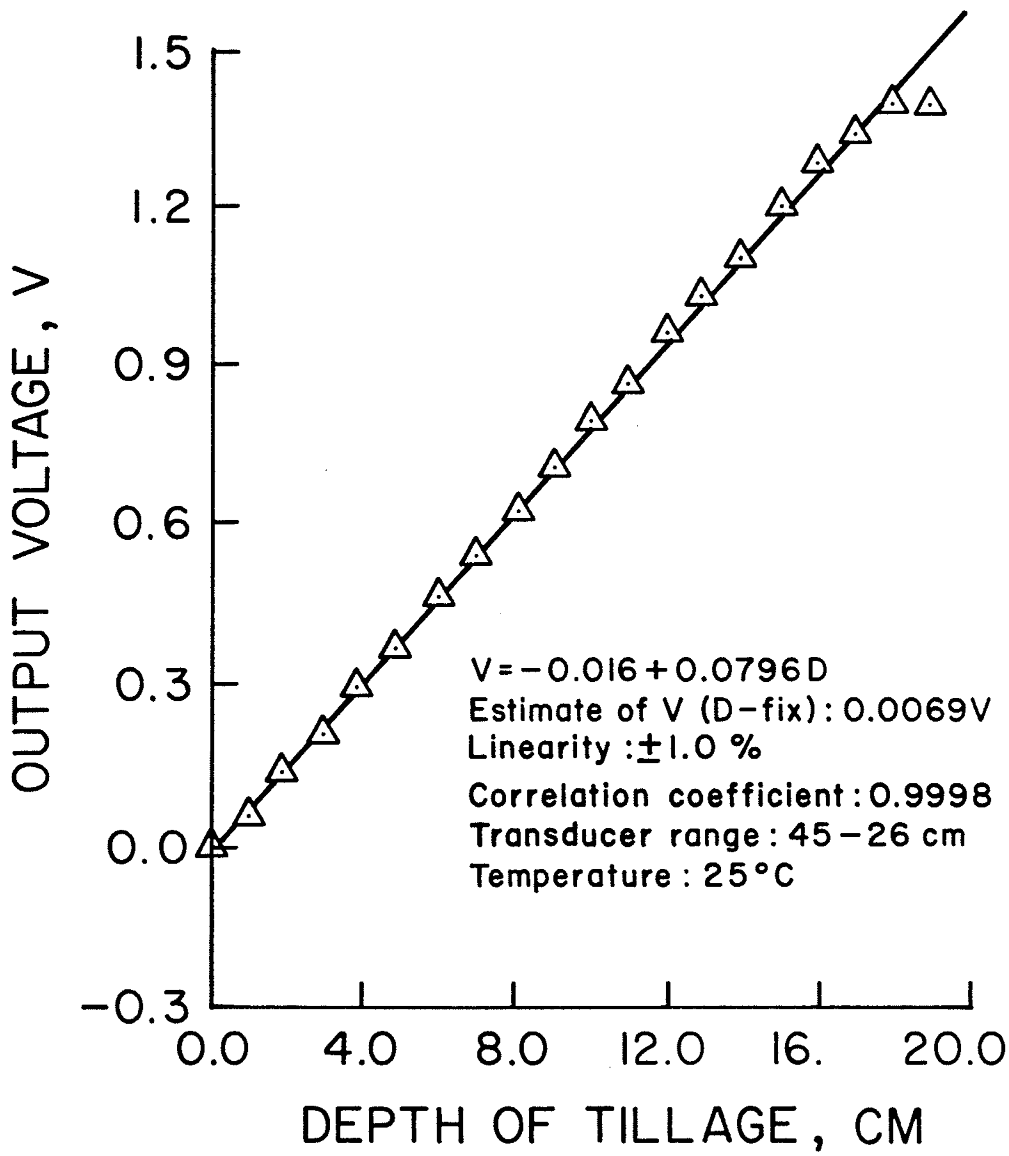


Figure A.2.2. Calibration curve for the steel surface. Points beyond 17 cm are excluded from the equation.

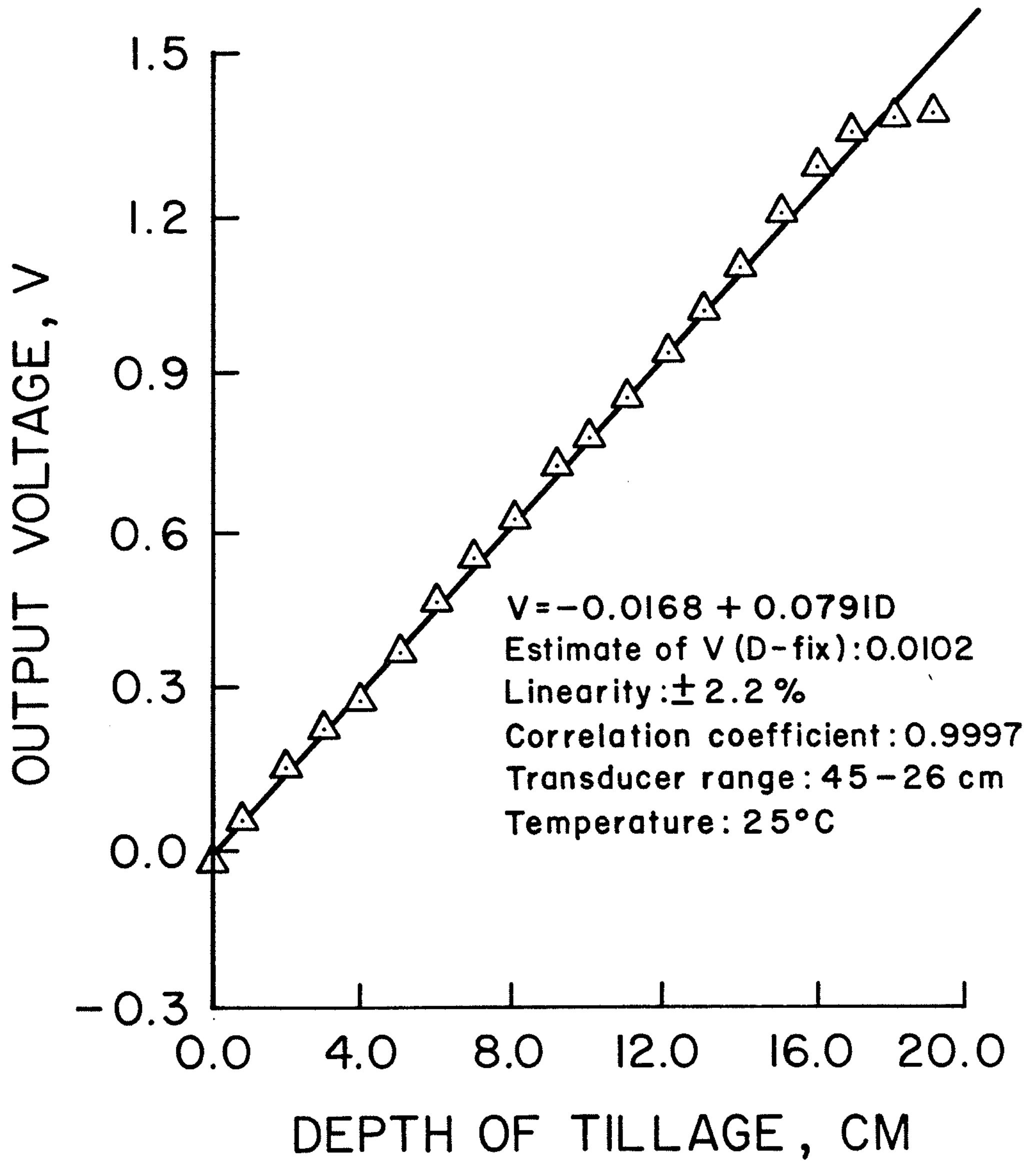


Figure A.2.3. Calibration curve for the water surface. Points beyond 17 cm are excluded from the equation.

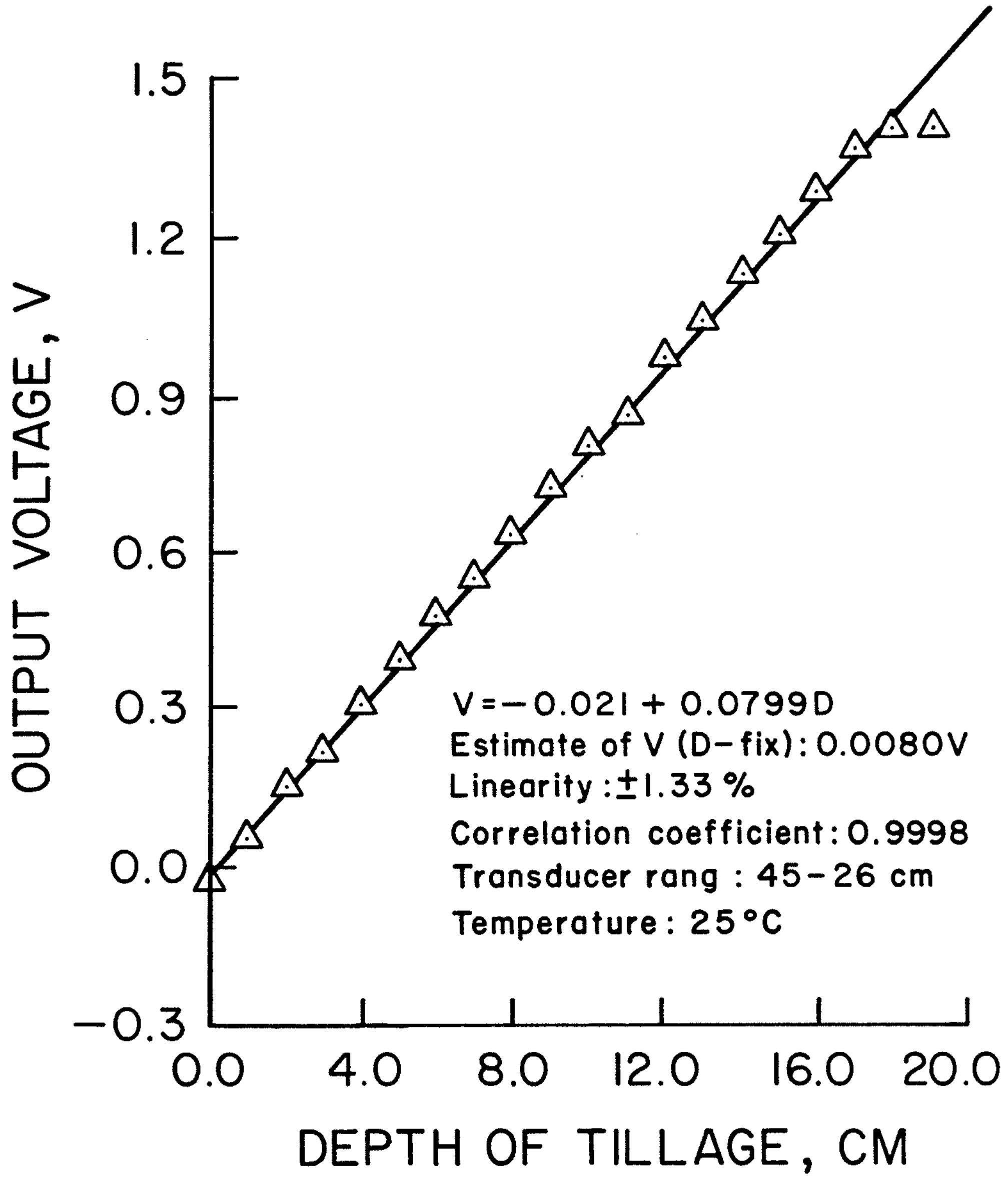


Figure A.2.4. Calibration curve for the sandy loam surface (15 moisture content on dry basis). Points beyond 17 cm are excluded from the equation.

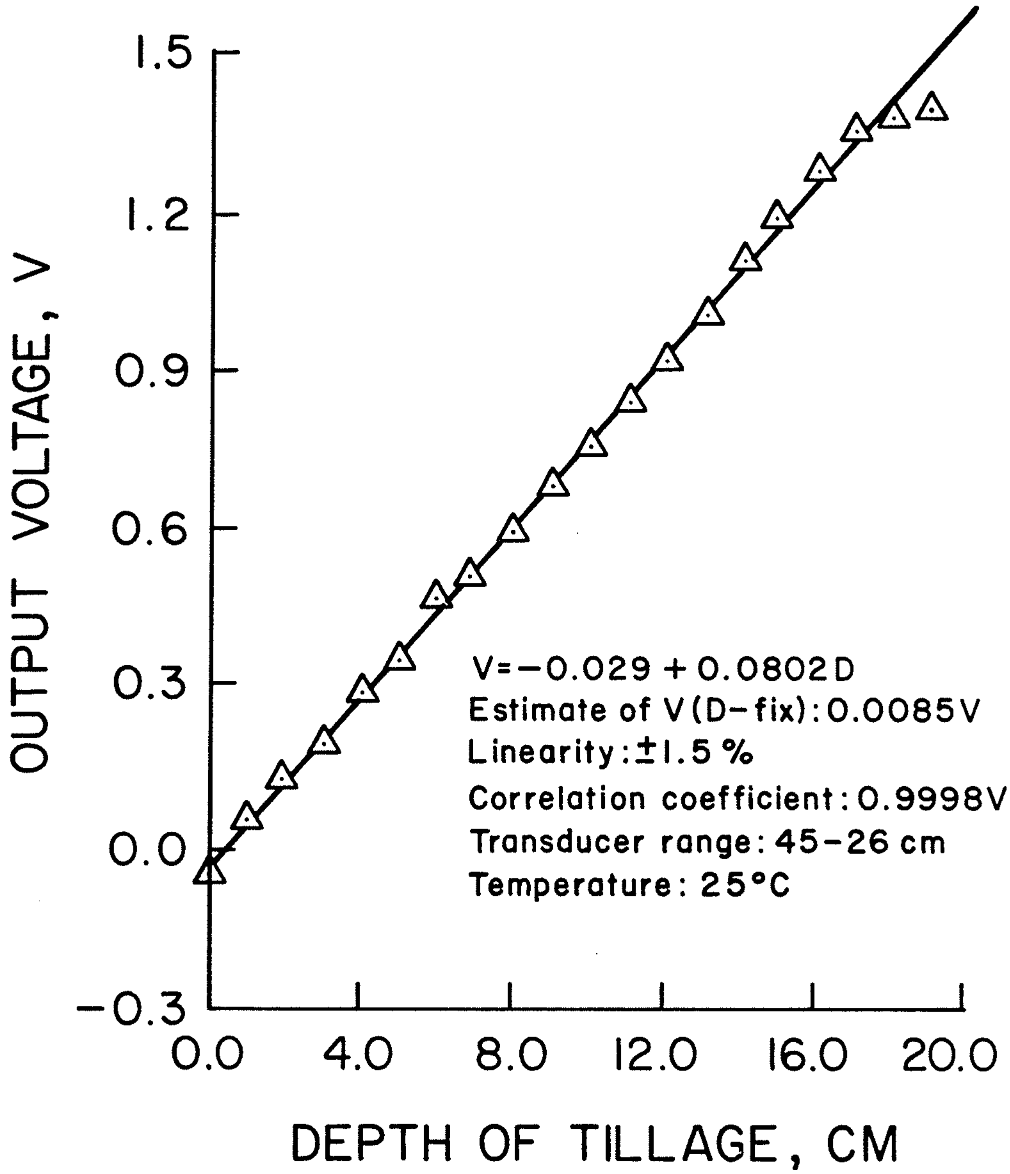


Figure A.2.5. Calibration curve for the Red River clay surface (8.4% moisture content on dry basis). Points beyond 17 cm are excluded from the equation.

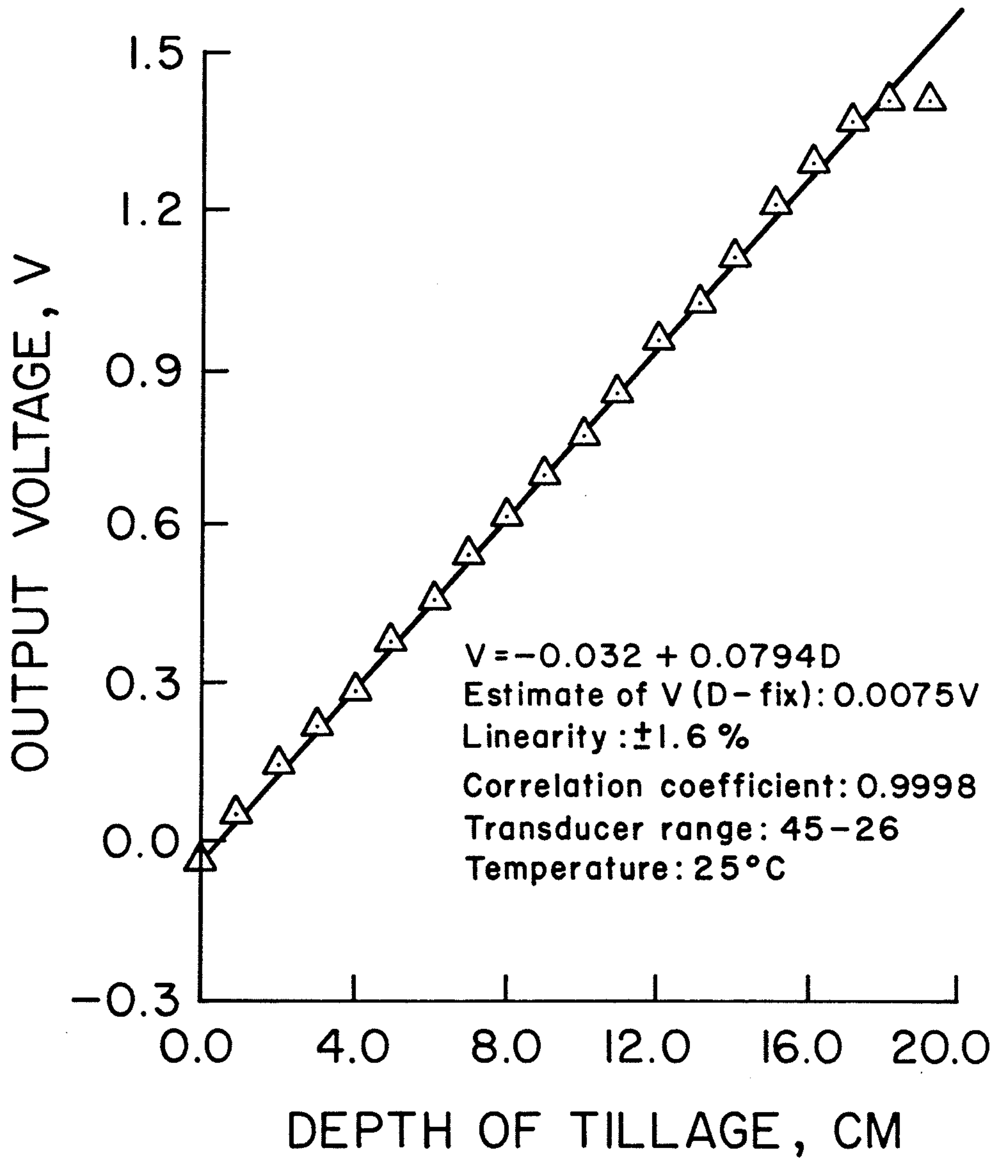


Figure A.2.6. Calibration curve for the Red River clay surface (50.2% moisture content on dry basis). Points beyond 17 cm are excluded from the equation.

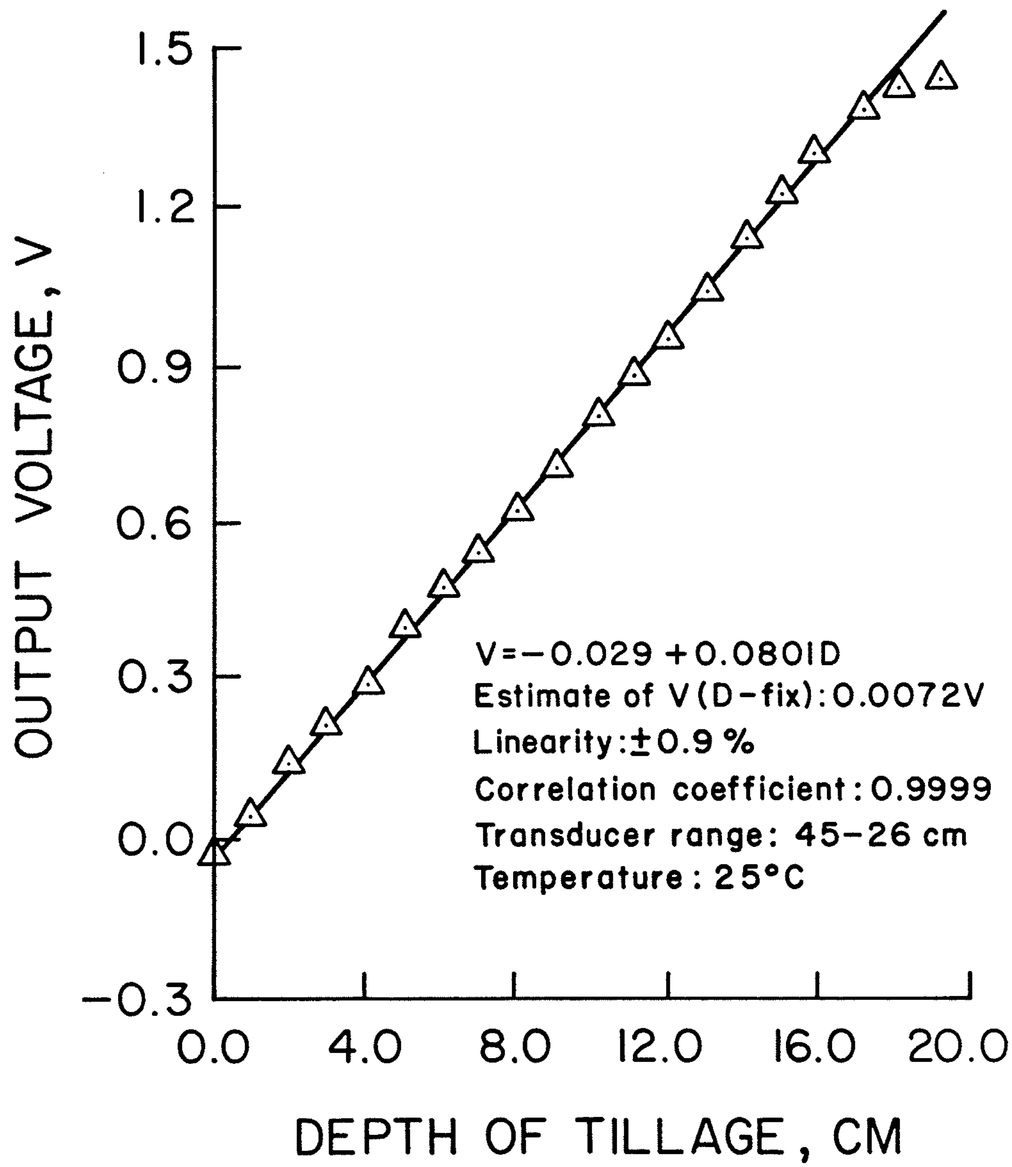


Figure A.2.7. Calibration curve for the peat soil (253.3% moisture content on dry basis). Points beyond 17 cm are excluded from the equation.

APPENDIX B

Appendix B.1

The SAS (Statistical Analytical System) program utilized to perform linear regression of the data obtained on plywood, steel, water, sandy loam, clay and peat soil surfaces.

```
//SENSOR JOB ',,,','KARAN'
//EXEC SAS79,SIZE=512K
//SYSIN DD *
DATA METCALB;
INPUT DEPTHCM VOLTIND VOLTDCD;
CARDS;
PROC SORT ; BY DEPTHCM;
PROC PRINT N D; VAR DEPTHCM VOLTIND VOLTDCD;
TITLE 1 **THE CALIBRATION DATA FOR THE DEPTH SENSOR**;
TITLE 2 THE SURFACE IS PLY WOOD;
DATA METERVD; SET METCALB;
RENAME VOLTIND=VOLT;
DATA METERVD; SET METCALB;
RENAME VOLTCDC=VOLT;
PROC SORT; BY DEPTCM;
DATA METERV; SET METERV1 METERVD; BY DEPTHCM;
PROC PRINT DATA=METERV  N D; VAR DEPTHCM VOLT;
TITLE LINEAR REGRESSION FOR THE DEPTH SENSOR;
PROC GLM DATA=METERV ;
MODEL VOLT=DEPTH CM/SOLUTION P CLI CLM;
TITLE LINEAR REGRESSION OF THE SENSOR FOR THE DEPTH OF PLOUGHING;
```

Appendix B.2

The SAS (Statistical Analytical System) utilized to perform linear regression by pooling data from all the tests in Section 4.2.

```
//SAS7 JOB ',,,','KARAN'
//EXEC SAS79,SIZE=512K
//SYSIN  DD *
DATA CALB;
INPUT DEPTHCM VPI VPD VSI VSD VWI VWD VRSI VRSD VRSHI VRSHD
VSLI VSLD VPSI VPSO;
CARDS;
PROC SORT; BY DEPTHCM;
PROC PRINT N D; VAR DEPTHCM VPI VPD VSI VSD VWI VWD VRSI VRSD VRSHI
VRSHD VSLI VSLD VPSI VPSD;
TITLE 1 --*THE CALIBRATION DATA FOR DEPTH SENSOR*--;
TITLE 2 CALIBRATION BY POOLING DATA;
DATA CPI; SET CALB;
RENAME VPI=VOLT;
DATA CPD; SET CALB;
RENAME VPD=VOLT;
DATA CSI; SET CALB;
RENAME VSI=VOLT;
DATA CSD; SET CALB;
RENAME VSD=VOLT;
DATA CWI; SET CALB;
RENAME VWD=VOLT;
DATA CWD; SET CALB;
RENAME VWD=VOLT;
DATA CRSI; SET CALB;
RENAME VRSI=VOLT;
DATA CRSD; SET CALB;
RENAME VRSD=VOLT;
DATA CRSHI; SET CALB;
RENAME VRSHI=VOLT;
DATA CRSHD; SET CALB;
RENAME VRSHD=VOLT;
DATA CSLI; SET CALB;
RENAME VSLI=VOLT;
DATA CSLD; SET CALB;
RENAME VSLD=VOLT;
DATA CPSI; SET CALB;
RENAME VPSI=VOLT;
DATA CPSD; SET CALB;
RENAME VPSD=VOLT;
PROC SORT; BY DEPTHCM;
DATA TOGETHER;
SET CPI CPD CSI CSD CWI CWD CRSI CRSD CRSHI CRSHD CSLI CSLD CPSI CPSD;
BY DEPTHCM;
PROC PRINT DATA=TOGETHER N D; VAR DEPTHCM VOLT;
PROC GLM DATA=TOGETHER;
MODEL VOLT=DEPTHCM/SOLUTION P CLI CLM;
TITLE LINEAR REGRESSION OF THE DEPTH SENSOR DATA;
```