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Final Report SRDC Project

Project JCU019

Close-range, Microwave Radar for Automatic Control of Base-cutter Height and Other Cane Harvester Operations

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Contents

Summary

The harvesting of sugar cane is the first stage in the commercial milling of cane to produce sugar. It is well known that harvesting plays a major role in determining the overall efficiency of the sugar production process. In Australia, where virtually all sugar cane is harvested using mechanical harvesters, efficient operation of the harvester is paramount to good sugar production. One area of harvesting that has been identified as an impediment to improved harvester effectiveness is proper adjustment of the base-cutter height. Improper base-cutter setting during harvesting has a number of serious consequences for sugar production including reduced production, crop damage, additional harvester running costs and inefficient transport and milling of cane through the introduction of dirt.

The overall aim of this thesis was to develop a ground detection sensor based on microwave radar technology that could sense ground level in front of a working cane harvester. The eventual purpose of such a device would be to automatically control the base-cutter height on the cane harvester to the optimum level and so improve the efficiency of the current harvesting, farming and milling processes.

The measurement technique investigated was based on the use of a radio transmitter and receiver positioned on either side of the row of cane. The assumption was a receiver close to the ground experiences more blockage from the ground than a receiver well above ground level. Thus, it was believed that changes in received level with height could be used to detect changes in the ground position.

The project evolved in two main phases. Initially, work concentrated on verifying the sensing principle in the laboratory and later in the field. Testing verified the proposed measurement procedure with the following major conclusions. Firstly, for best results a radio signal of around 2-3GHz polarised horizontal to the ground was most suitable. This type of signal provided the best compromise between being insensitive to the presence of the cane while still allowing practical sized antennas to be employed. Secondly, field-testing showed that the cane does still effect the ideal sensor response with the orientation and condition (density, leaf matter, etc) of the cane having a noticeable influence on the measurements. These results suggested that a practical sensor would need to incorporate automatic compensation for the presence of cane and that some averaging would have to be applied to remove the random fluctuations from the underlying trends.

The second stage of the project involved the building of a prototype sensor and its' testing on a working cane harvester. A new type of microwave ground detection sensor was developed. This device works by measuring the amplitude of a 2.4GHz, horizontally polarised microwave radio signal sent from one side of the cane row to the other. For this application, multiple receivers are stacked vertically to measure the full height profile instantaneously. The idea of using multiple receivers with some set well above ground level, was to compensate for the changing density of the cane. The transmitter and receiver antennas were based on rectangular patch arrays. The low profile of these patch antennas were ideal to be mounted flush to a harvesters' crop divider walls. Dedicated transmitter and receiver electronics was built to generate and detect the microwave radio signals used by this system. A test system using a laptop IBM PC and running a Visual Basic 6 program to control the operation of the sensor and log results, was also developed.

The prototype sensor developed was trailed on an Austoft harvester over a one week period in the Burnett region. The main conclusions of these tests were that the sensor did work and that it could survive the harsh conditions experienced on the harvester.

Operational characteristics like accuracy and range could not be determined due to the lack of any independent measure of ground height while on the harvester.

In conclusion, this work showed the potential of developing the microwave ground detection sensor for control of base-cutter height onboard cane harvesters. This report also identifies the suggested future path to take in developing a fully operational base-cutter height control system.

Chapter 1 Background

1.0 Introduction

Sugar cane is the main agricultural crop grown in Queensland. About ninety-five percent of all raw sugar produced in Australia comes from Queensland. Last year, 4.14 million tons of sugar was produced from around thirty million tons of raw sugar cane [1]. Sugar is the second largest export crop for Australia and is estimated to be worth $1 billion to the Australian economy (based on the 1999/00 season). Australia produces four percent of the worlds' sugar but exports the majority of this totalling twelve percent of the worlds' raw sugar trade each year. Ninety-nine percent of this exported sugar is supplied by the Queensland sugar industry.

The deregulated world sugar market is a volatile market and if the Australian sugar industry is to remain competitive, then it must optimise the efficiency and profits of all aspects of the production process. High labour costs for the Australian workforce also affect the profitability of the industry, and automated processes are needed to achieve high efficiency, produce better quality product and increase profits.

The harvesting and transport of cane has been identified as having a major influence on the efficiency of the whole industry [2]. In particular, inaccurate setting of the base-cutter height and the subsequent collection of dirt with the cane is known to be a limiting factor in sugar production. Previous studies have indicated that increased cutting accuracy will lead to reduced costs for the sugar refining mills, and increased sugar quality for farmers [3]. By achieving precision control over this single parameter, farmers, millers and harvester contractors could expect to obtain greater returns due to reduced operating costs and higher sugar production. It is not surprising then that the automatic control of the harvester base-cutter depending on the ground height has been a long-time goal of the Australian sugar industry.

1.1 Problems Associated with Inefficient Base Cutter Height Control

Inefficient harvesting methods affect all the major sectors of the Australian sugar industry. The three sectors of the Australian sugar industry being : -

- The farming sector, which produces the sugar cane,
- The harvesting sector, which harvests the sugar cane and
- The milling sector, which transport and processes the sugar cane.

The effects of inefficient height control upon these sectors, including estimates of additional expenses from dirt in the cane supply, are described below. It should be noted however, that the costs estimates provided here are based on extrapolation of old data and assume reductions in dirt levels will provide proportional deceases in costs. Obviously, these assumptions will not be completely valid but certainly the figures quoted do give some indication of the magnitude of the problem.

1.1.1 Benefits to the farming sector

The process of mechanical harvesting can cause problems if the cane is cut either too high or too low with respect to ground level. When the cane is cut too high, the stalks of the cane may shatter introducing disease into the plant causing a loss of production in the following year. On the other hand, if the cane is cut too low, the stool, or the root system, may be damaged leading to similar results. In either case, instead of being able to achieve four seasons' growth from the same plant, earlier replanting may be required.

It has been shown that during the raw sugar refining process, the Commercial Cane Sugar, CCS, level is degraded in proportion to the percentage of dirt in the harvested cane [4]. The lowered CCS level signifies that a reduced quantity of raw sugar is produced per ton of cane. The reduction of the CCS level affects the farmers directly as the price paid to the producer is linked to the CCS level of the cane taken to the mill.

Ultimately the use of automatic base cutter height control would optimise the return per ton, by maximising the CCS levels. Correct base cutter control will also result in less damage to ratoon cane and therefore increased ratoon yield in subsequent years. Less disruption to the ground will also reduce soil erosion.

1.1.2 Benefits to the harvesting sector

The base-cutters on modern harvesters are located directly below the harvester cabin, well out of the view of the operator. Automatic control of the base cutter would mean that the base cutter height would be adjusted to track changes at ground level. This is something that is obviously not possible for the operators to do currently.

The power of modern harvesters makes it possible to cut well below ground level with no noticeable effect on the speed, or other indicators on the harvester. Again however, there is a down side to cutting too low due to increased wear and tear on the machinery, particularly the base cutter blades. Unnecessarily loading the machine also increases running costs through extra fuel and oil usage. Despite this, anecdotal evidence suggests most farmers request contactors cut their cane below ground level to presumably give them the best return.

Automatic control of the base-cutter height should lead to reduced wear for the cutting blades and less maintenance and running costs for the harvester. However, the full improvement will only be possible if farmers and harvester operators can be convinced of the benefits of proper height settings.

1.1.3 Benefits to the refining sector

With up to 40 million tonnes of cane being processed each year in Australia, even a small reduction in milling costs will translate into significant savings to the sugar industry. In 1986, Mason and Garson performed an investigation into the extra costs associated with the milling of sugar cane contaminated with dirt [6]. It was concluded that the cost to the mill was around $0.62 per tonne of sugar cane to maintain the milling facilities. Assuming that the Consumer Price Index has increased by three percent over the last fifteen years, the cost today would then be around $0.97 per tonne for additional mill maintenance.

Assuming the current average dirt ratio of around 1.7 percent [5], it can be estimated that by reducing this level to around 0.5 percent by optimising the cutting height, a total saving of approximately $0.68 per tonne to the sugar milling community could be expected. This figure corresponds to an estimated reduction in running costs to the milling sector of up to $27 million each year.

These figures are based solely on maintenance costs to the milling sector. In practice, in addition to these costs, there is extra expenditure associated with the transport of extra material to and from the mill, reduced sugar quality and quantity, and extra wear on plant. These factors mean that the actual cost to the milling sector are much greater than those estimated above.

1.2 Background

Every since the introduction of the mechanical harvester, there has been a steady increase in the level of dirt in the harvested cane transported to the mills [5]. One factor that has contributed to this rise is the increased power of modern harvesters. With a more powerful machine, it becomes easier to cut at a lower level because the operator does not experience any adverse side effects like a reduction of speed when cutting below ground level. Harvester operators are therefore more inclined to err towards cutting on the low side to satisfy the farmers desire to maximise their crop. Another reason for increased dirt levels seems to be the common perception amongst the farming community that cutting lower improves profits through a greater bulk of material being collected. This view remains common despite recent studies having shown the trade off in adding more dirt to the cane will often result in reduce profits due to a lowering of the CCS [4].

Current thinking on the introduction of automatic base-cutter height control to the harvester, is that this system will probably be similar to a cars' cruise control system. That is, the operator will be free to set the base cutter height to the level that he (or the farmer) desires, the control system will simply try to maintain the set position with respect to the ground. Obviously then, improvements in the reduction of dirt in cane will depend largely on the proper use of this technology and thus whether operators and farmers can be convinced of the benefits of trying to reduce dirt levels. However, these concerns were not the focus of this project. One immediate benefit of an automatic base-cutter height control system though will be the problem that the operator cannot continually adjust the base-cutter height to track small changes in ground height, will be overcome. An automatic system would make it possible for the operator to use a "set and forget" approach confident in the knowledge that the base-cutter height was being adjusted to follow the ground contours at the specified cutting height.

1.2.1 Sensing techniques

Currently, Australian cane harvesters use no form of automatic base-cutter height adjustment. The harvester operator is required to manually adjust the base-cutter level from within the cabin. However, due to the positioning of the base cutters directly below the harvester cabin, the operator is unable to directly observe the cutting height. It seems that most operators therefore adjust the base-cutter based on "experience" though some claim they make adjustments using a combination of a visual inspection of the row profile behind the harvester and/or by observing the pressure reading of the base cutter's hydraulic motor. In any case, it is clearly very difficult to accurately determine the current base-cutter height setting from in the harvester cabin, and thus the setting is rarely optimal. Moreover, it would be physically impossible to make the many small adjustments manually that would be required to track the ground profile over the length of the paddock, even if one could accurately judge the current base-cutter setting relative to the ground.

There have been a number of proposals over the past twenty years or so of ways to control the cutter height on mechanical harvesters. It appears that most of these approaches have had limited success due to the difficult measurement environment involved. From a control point of view it is highly desirable to measure the ground height in front of the base-cutter so the cutter can be adjusted to suit the future ground height profile. However, when sensing the ground height in front of the base-cutter, a sensor has to contend with the presence of the cane. The cane stalk and leaf can obscure a sensors "view" of the ground or may cause fouling, even damage, to the sensor. Measuring ground height behind the base-cutter has the advantage that most of the cane is removed and the sensor will have a clearer view of the ground. On the other hand, if measuring behind the cutter, the passing of the cutter nearly always disturbs the ground level and it may be difficult to get an accurate ground level reading. Furthermore, the lag between cutting the cane and measuring the ground height, means the control system is continually playing "catch up" and hence will not perform well if there are rapid changes in ground height.

There are two distinct classes of devices that have been tested for base-cutter height control. One style of device that has been tried in many different forms can be broadly termed a "mechanical contact sensor". This type of sensor might use a skid or wheel to gauge the ground height [7]. Generally, this type of sensor suffers from fouling from the cane, leaf and mud found around the base-cutter region on the harvester. The other style of ground level detection sensor can be broadly labelled a "non-contact sensor". This type of sensor attempts to determine the ground position by detecting changes in a field or a travelling wave that interacts with the ground. Some sensors of this type include ultrasonic sensors that measure delays to a sound wave or radar sensors that detect variations in a travelling electromagnetic wave. The main advantages of the non-contact type sensors are that the measured quantity does not disturb the ground level and there is less chance of fouling, as the sensor head does not physically contact the ground or the cane. For similar reasons, non-contact sensors also tend to require less maintenance to keep them operating.

Some different measurement approaches that have been investigated in the past are described below.

1.2.1.1 Mechanical contact sensors

Simplicity is often the best technique, and measuring the ground height using a skid or wheel at first seems the most practical and logical concept of all. However, to date most of these types of sensors have had little success. Mechanical sensors in front of the base cutters are usually unsuitable due to interference from trash, mud, and even the cane itself [8]. Trash and debris is often caught in the device causing jamming of the mechanical movement rendering the sensor useless. In some devices the skid or wheel uses a spring to maintain ground contact but in soft or muddy soil conditions, the spring drives the sensing device into the ground breaking or damaging it in the process. This problem is worse in areas where flood irrigation creates soft or muddy paddocks. Sugar cane can also grow along the ground, stopping the sensor from contacting the ground and hence giving an inaccurate reading.

Recently, a base cutter height control system being used on Brazilian cane harvesters has been publicised [9]. This system uses a “floating” base-cutter arrangement with a raised dome “hubcap” below the cutters to raise the cutter height when the ground level increases, Figure 1.1. This type of system obviously measures behind the base-cutter, which is less desirable from a control point of view. Also it is not clear how this approach could be adapted for Australian cane harvesters where the base-cutter is essentially fixed to the harvester cabin. Furthermore, no information is available on how this device might operate in soft or muddy conditions. Never the less, this is an interesting idea and it would be worth investigating this approach further.

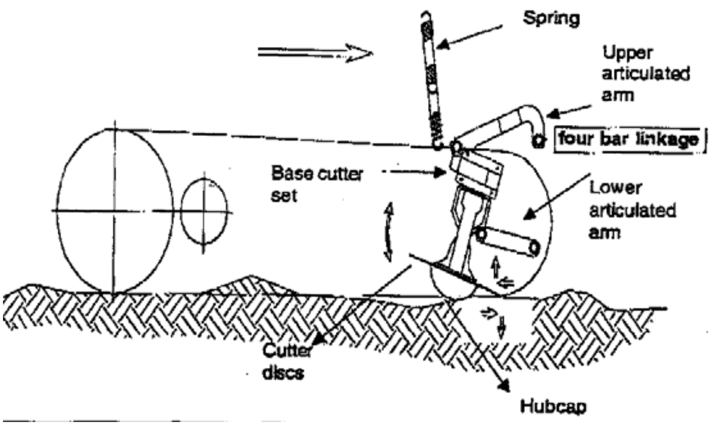

Figure 1.1

1.2.1.2 Hydraulic pressure sensing

This technique involves monitoring the pressure across the hydraulically driven base-cutter motor. In theory, the pressure should vary as the base-cutter starts to cut more deeply through the more dense ground [8]. The base-cutter essentially becomes the mechanical contact sensor in this approach. Unfortunately, more recent studies [5] have shown that the base-cutter pressure does not vary in a predictable manner. In particular, the base-cutter pressure was found to vary non-linearly with both the cutting height and the harvester’s travel speed, making it difficult to use this method with any confidence. At best, it seems this technique will only be useful as a crude indication of when the base-cutter is working well below the ground level.

1.2.1.3 Ultrasonic sensor

In this approach, an ultrasonic signal is transmitted and subsequently reflected by the ground. The time difference between sending a signal and receiving a reflection is then measured and used to determine the distance travelled. The Sugar Research Institute, SRI, has been investigating the use of ultrasonic detection for base-cutter height control for a number of years [5]. Their investigations have shown that if the cane is cut green or only partially burnt, then the trash surrounding the stool often blocks the ultrasonic signal. Since most cane is now cut green, there seems little possibility of using an ultrasonic sensor in front of the base-cutter. Investigators at SRI have had better success using ultrasonic technology when installed in a position not prone to blockage from cane trash. For base-cutter control then, a sensor location behind the base-cutter appears the only real option and, as mentioned earlier, is not ideal from a control perspective.

1.2.1.4 Microwave measurement technique

Microwaves, being an electromagnetic wave, will penetrate most materials (except conductors) to differing degrees. A microwave ground detection sensor for use on board a cane harvester is therefore attractive from the point of view that such a device might be suitable for use in front of the harvester base-cutter. Work on a microwave radar system for this application has been reported [10]. The researchers examined a dual-frequency radar measurement technique at a frequency of around 1GHz. However, this work was all conducted in the laboratory and no conclusive results were obtained.

More recently, Ruxton conducted preliminary research into a microwave ground detection system for the base-cutter control application [11]. Ruxton's laboratory experiments showed that a microwave radar system that measures reflections off the ground was not suitable because of interference from strong reflections from the cane. However, it was shown that a "transmission style" sensor might be applicable to this application. A measurement technique was proposed where the attenuation of a microwave signal transmitted just above the ground was measured. In this configuration, it was found that the signals were reasonably insensitive to the presence of the cane but that the attenuation increased sharply as the antennas approached the ground level. Further investigations into this approach were conducted in 1999 by Page [12] to ascertain the optimum operational frequency and antenna specifications for this sensing technique. This research led to operational specifications including the best measurement frequency range, antenna beamwidth, antenna polarisation and correct equipment configuration for the current sensing system.

This approach has been further investigated in the project described in this report [13,14]. The work was funded by an SRDC grant between July 1999 and July 2002.

1.2.1.5 Other sensors

There are undoubtedly other sensor types that could be considered for this application. Obviously though it is best to investigate the simplest, cheapest and safest approaches first.

Another approach that to the author's knowledge has not been tried as yet in this application is a nuclear sensor. The radioactive decay of a nuclear material can be measured through virtually any material, including metals. By measuring the energy of the radioactive particles that escape from a source in different directions, it is possible to judge the density of the medium through which the particles have travelled. It might therefore be possible to distinguish between paths where the particles passes through just cane say to where the path includes a proportion of more dense material like ground. In this way, the level of the ground might be sensed in front of the base-cutters. The main advantage (and disadvantage too) of a nuclear sensor is that the radioactive particles will penetrate virtually any material, making this type of sensor suitable in even the most difficult measurement applications. Obviously, when using a radioactive material there are always some safety concerns that make this approach a last resort.

1.3 Aims

The aims of this study as proposed in the original project application were to;

1. To determine the optimum operating frequency range and polarization state of a microwave sensor to measure ground level through cane.

2. To test various sensor configurations for this application in order to find the optimum arrangement.

3. Build a prototype microwave ground detection system, which can operate in the harvester environment, and is suitable for control of the base-cutter height and other cane harvester operations.

To achieve these objectives the first step taken was to verify that the microwave transmission sensor approach was suitable for the base-cutter height control application. This was to be done through a series of laboratory and field tests. These preliminary tests were also to be used to determine how best to configure a sensor for use on a harvester.

The second major stage of the project was concerned with the building of a prototype sensor and its testing while on a working cane harvester. While it would be nice to have been able to have a working system used on board a harvester to control the base-cutter height, this is a large step, and was not an aim of this study. What really was to be achieved was to check the suitability of a microwave ground detection sensor for this application. Control of the base-cutter based on the new sensor and testing of the effectiveness of this approach is a topic for future work.

The ground detection sensor investigated in this application was primarily designed for base-cutter height control. However, there are a number of different systems on board a harvester where ground height measurements might be usefully employed to better control the harvesters operation. Some other applications include row divider height control and positioning of the harvester central to the cane row. Although the described sensor might be useful in these situations, these applications were not explicitly examined in this project.

Chapter 2

Laboratory Testing

2.0 Introduction

The first stage of this project was concerned with testing the sensing technique in the laboratory. The work by Ruxton and Page [11, 12] had shown that the only viable measurement approach was a transmission style configuration, Figure 2.1. This project therefore started with this configuration and worked towards determining the best frequency, polarisation and antenna specifications when employed in the base-cutter control application. This part mainly concerned finding the best system specifications to respond to the presence of the ground, yet be insensitive to the cane. Again, some previous work was relevant to this objective and so some earlier results are recapped in this report.

Before the results of these tests are reported though, this section includes a description of computer simulation of the proposed measurement system. Although not a stated aim of this project, this work was considered useful to give a better understanding of the measurement principle and what system parameters effect the operation.

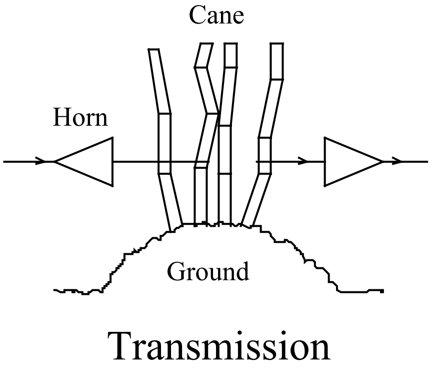

Figure 2.1 : Transmission configuration of microwave ground detection sensor

2.1 Simulation Results

2.1.1 Knife Edge Diffraction Model

Before experimental measurements were made, a simple theoretical model for this measurement situation was examined. This model was based on the theory of “knife-edge diffraction” of electromagnetic waves [15]. In this model the cane was totally neglected and the cane root mound was considered as a “thin conductive sheet”, Figure 2.2. The coarse assumptions used in this model meant that very accurate results were not expected but it was hoped that this model would provide some qualitative insight into the operation of the proposed sensor. The equation describing loss between the transmitter and receiver in this model is;

$$\begin{aligned} Loss(dB) &\approx -6.65 - 8.19v + 0.98v^2 \quad \text{for } -0.75 \le v \le 3, \qquad (1) \\ &= 0, \quad v < -0.75 \end{aligned}$$

where $v = h\sqrt{(2/\lambda)(1/d_r + 1/d_t)}$

and λ is the free-space wavelength and *h* is the distance between the top of the knife-edge obstacle and the direct path between the transmitter and the receiver. It is negative if the direct ray passes over the obstacle. d_r is the distance between the transmitter and the obstacle and d_t is the distance between the obstacle and the receiver.

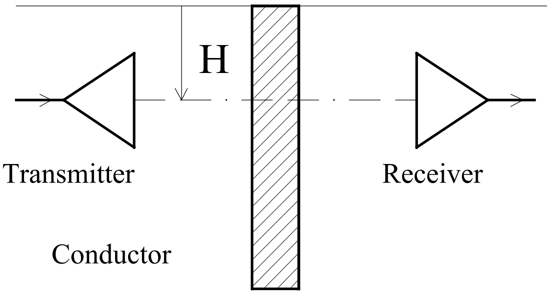

Figure 2.2 : Knife edge diffraction model of ground detection sensor

This model therefore predicts the amplitude of the received signal level with respect to the ground level. Some predictions obtained using this model are shown in Figure 2.3. The figure shows the predicted attenuation versus height at frequencies of 10.3GHz, 4.1GHz and 3.275GHz. The three frequencies at which the model was applied were chosen to be the same as the frequencies that would be used for the experimental tests.

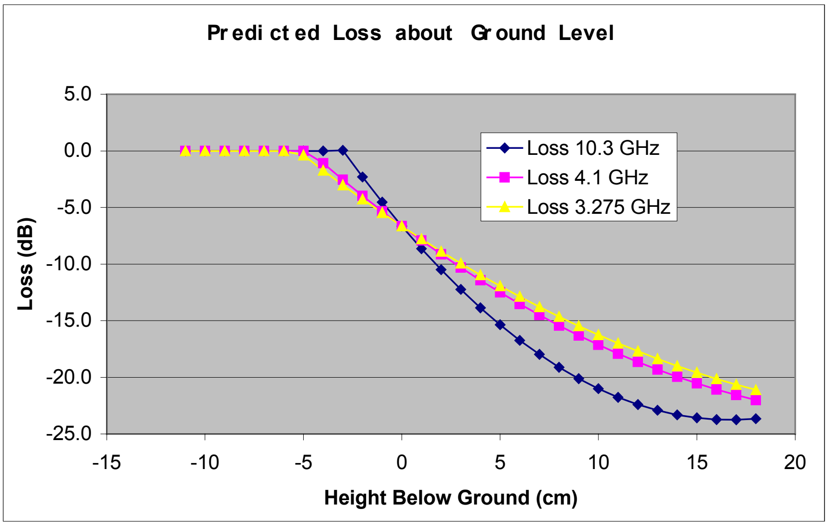

Figure 2.3 : Predicted signal loss above and below ground level assuming a “knife-edge” obstruction.

Observing the results obtained in Figure 2.3 it is clear that this type of sensor should be sensitive to the ground height. All three frequencies at which the model was applied show that the amplitude of the received signal drops as the antennas approach and go below the top of the “ground mound”. Above the top line of the obstacle, small attenuation is experienced, while below this line, the field drops away gradually as the height decreases.

With such a coarse model as the one used here, the accuracy of the model will not be particularly good. Having said this, this theoretical model is useful to gain some insight into the characteristics of this type of sensor. For example, Figure 2.3 shows that lower frequency sensors will provide a useable output for greater heights above the mound level. This type of result can be useful when choosing the operating frequency for a sensor that must be mounted at a certain minimum height above ground level because of the physical constraints of the cane harvester construction.

2.1.2 Electromagnetic Field Simulation

The knife-edge diffraction theory described above assumes an obstacle consisting of a thin, highly conductive metal wall. In this application though, the obstacle is the cane root mound, which is neither "thin" nor a highly conductive medium. There may therefore be some question about the validity of this model for this situation. To give a better appreciation of how the ground detection sensor might respond in the actual measurement conditions to be encountered in a cane paddock, an electromagnetic field simulation was required. A field model of the ground detection sensor was carried out using a full-wave, two-dimensional, electromagnetic simulator program called "Real Time" [16]. This simulation program is based on the Finite-Difference Time-Domain (FDTD) technique and illustrates the propagation of electromagnetic waves including reflection and diffraction effects.

The first test performed with the field simulation software was a repeat of the diffraction test mentioned above but assuming a "real" ground profile and characteristics. The situation simulated is shown in Figure 2.4.

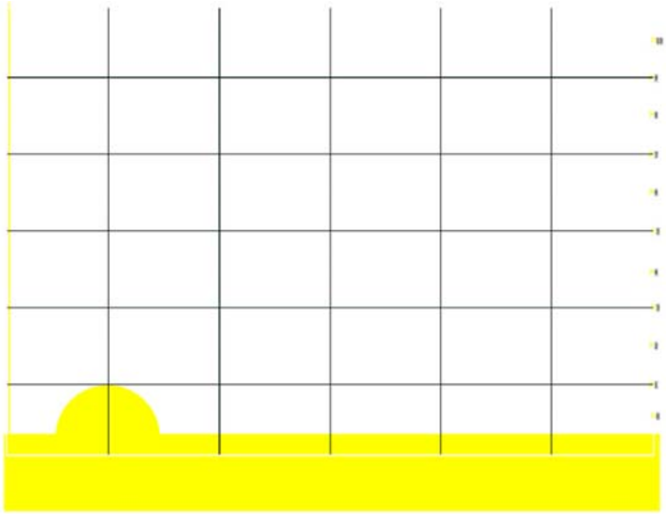

Figure 2.4 : Diffracted field simulation configuration

The simulation performed assumes a plane wave field at 2.5GHz propagating from left to right in Figure 2.4. The field is polarised so as to be out of the page or horizontal to the ground. The position of the ground and the cane root mound are shown in yellow in this figure. The ground was assumed to have a dielectric constant of 8 and a conductivity of 0.0011. These values were chosen to represent what might be classified as "moist soil". The grid lines shown in Figure 2.4 are 100mm apart and thus the ground mound was assumed to be fairly low, less than 100mm high. The effect of the ground on the field was measured at the extreme right of the figure using probes located at different heights. The probes where aligned to be about 500mm from the root mound to simulate the sort of spacing which might be expected at the front of a cane harvester. The probes where located about 50mm apart in height with the first probe set about 20mm above ground level. The highest probe was just over 500mm above ground level.

The field intensity at the end of the simulation period for the configuration shown in Figure 2.4 is shown in Figure 2.5. Regions of dark red and blue show areas where the field is strongest while the colour white represents a position where the field is zero. The red and blue colours show the different polarity of the field, positive or negative. The cyclic intensity of the field as it propagates from left to right is clearly seen as alternating red and blue bands. During the simulation, these bands progress from left to right as the field travels in that direction.

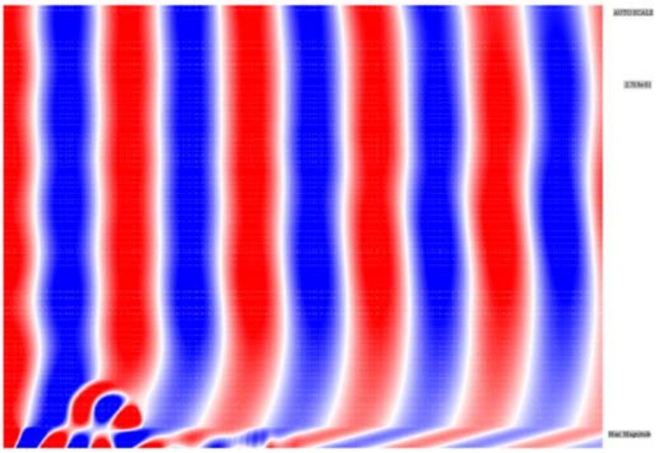

Figure 2.5 : Simulated diffracted field over ground mound

Towards the top of the figure, well away from the ground, the field is not affected by the presence of the ground. However, closer to the ground, the colours are a little lighter indicating the fields are weaker here. Essentially, this is what was seen in the knife-edge diffraction model. That is, as we approach the ground and go below the top of the obstruction, the field amplitude gradually decreases. A better view of the predicted change in field amplitude above the ground can be obtained by examining the responses measured by the probes located on the right hand vertical. The rms amplitudes are plotted in Figure 2.6.

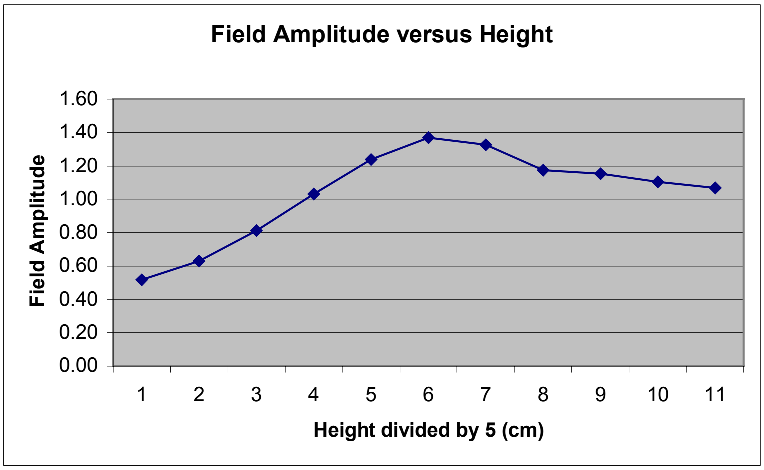

Figure 2.6 : Simulated field amplitude versus height

This curve is again very similar to the response predicted by the knife-edge diffraction theory and again gives some confidence that the microwave ground detection sensor should work as predicted.

In both the previous simulations, the effect of the cane was neglected when predicting the field amplitudes that would be measured above the ground. In practice though, the cane will have some effect on the measured fields. Unfortunately, the orientation and density of the cane will vary substantially throughout the cane paddock and hence a “typical” model may be difficult to produce. Furthermore, the field simulation software available for this project, only allowed 2 dimensional structures to be simulated, and could not therefore take into account both the ground and the cane at the same time.

In order to get some idea of the effect of the cane therefore, it was decided to do a simulation in the horizontal rather than the vertical direction. Thus, rather than simulating the field variation with height above ground, the field variation at a set height along a row of cane was performed. The configuration used for this simulation is shown in Figure 2.7.

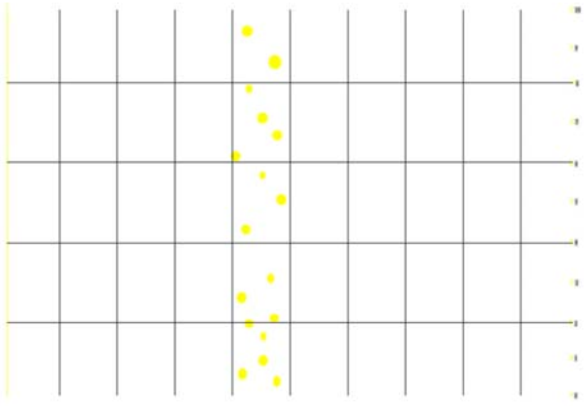

Figure 2.7 : Configuration used for horizontal field simulation.

This simulation is similar to before and involves the propagation of a 2.5GHz electromagnetic plane wave, from the left of the figure to the right. However, the vertical axis of this figure is now a position along the row of cane (rather than the height above the ground). The grid spacing is 100mm per division. The yellow dots at the centre of the figure are the cross sections of the cane stalks randomly placed along the length of the row. The electrical characteristics of the cane were taken to be; Dielectric constant 2, conductivity 0.03 [17]. The field is now polarised to be in the plane of the diagram, but because of the change of orientation, this again implies the field is polarised horizontal to the ground. The field at the right of the figure was measured at different points using probes. The 2-dimensional colour plot of the field intensities at the end of a simulation period is shown in Figure 2.8.

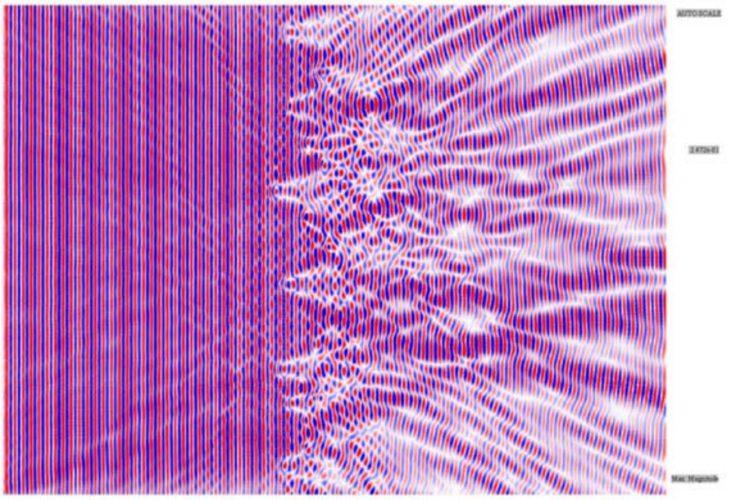

Figure 2.8 : Predicted field intensity along cane row.

Note that in the left hand half of the field plot, we basically obtain the alternating blue and red bands, characteristic of a travelling wave propagating from left to right without interference. As the field interacts with the cane at the centre of the diagram though, the colours tend to get lighter showing a general reduction in the field amplitudes on the right hand side of the cane. As well, there is a distinct streaking in this half of the diagram as the field follows multiple paths through the cane and recombines on the other side either in or out of phase. The significance of this simulation is that it shows the cane will attenuate the fields but that this attenuation need not be constant along the row. A different view of this simulation is obtained by considering the rms field amplitudes detected at the probes, Figure 2.9.

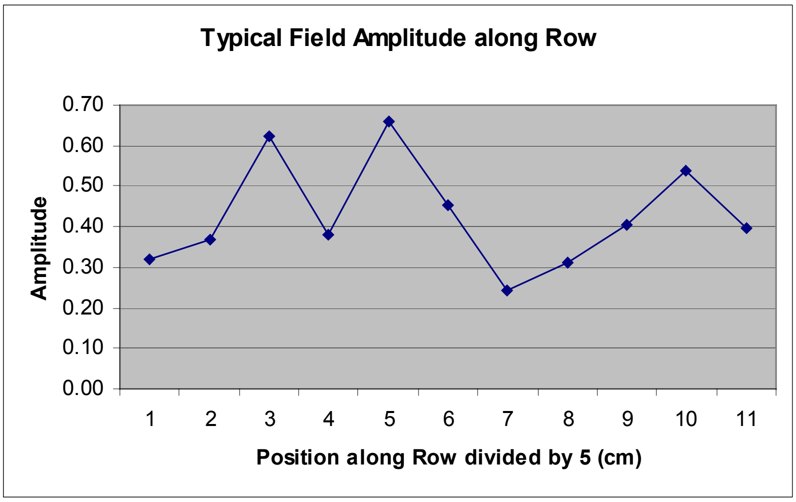

Figure 2.9

As expected this graph shows a random fluctuation in field level along the length of the row. This type of result implies that in a practical application, the cane causes a varying amount of attenuation and that some form of average may be needed to see the underlying trends.

It is tempting to investigate the simulation results further to try to establish averaging ranges and accurate levels as well. However, the focus of this project was a practical study and as such no further investigation was undertaken.

2.2 Laboratory Measurements

Having established theoretically a principle by which the ground height might be measured, it was then necessary to test this idea in practice. This was a very important stage and essentially took all the remainder of this project to complete. This particular section concerns measurements performed in the laboratory.

A laboratory system for testing microwave signal propagation around sugar cane plants their roots and the ground, was built for use at James Cook University. This system comprises a rectangular plastic tray on which a stool of cane can be positioned. The tray is braced and supported by ropes so that the tray and the cane stool can be manually raised and lowered using a block and tackle pulley system. To measure microwave signal transmission with respect to ground height, microwave horn antennas are mounted on either side of the cane stool while it is raised and lowered. A vector network analyser (HP 8722A) is connected via cables to the horn antennas and measures the signal transmission through the cane stool. Measurements are stored on a PC for later analysis.

Using the test system described above, signal transmission was measured at different heights above ground level. Tests were performed on three different cane samples and in three different frequency bands; S-band (2.6-3.95GHz), C-band (3.3-4.9GHz) and X-band (8.2-12.4GHz). In all cases the transmitted signal was horizontally polarised[1]. The three cane samples tested were from two different areas; one sample was from the Burdenkin and two samples from the Herbert region. The sample from the Burdenkin was striped of trash to simulate burnt cane. The Burdekin sample was quite thick (diameters between 2.5cm and 3cm) but was also quite old and was almost dead. The two Herbert stools were both alive but were somewhat different; one sample was reasonably thick (diameters between 2cm and 2.5cm) and had a lot of trash while the second sample was thinner (diameters between 1.5cm and 2cm) and had less trash.

Summaries of the results of tests performed on these samples are shown graphically in Figure 2.10. Figures 2.10(a)-(c) show the results for the “burnt” cane sample in the three frequency bands,

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[1] Ruxton established in a preliminary study that this was the preferred polarisation state to minimise interference from vertical cane stalks.

respectively. Figures 2.10(d)-(f) show similar results for the thick cane sample while Figures 2.10 (g)-(i) show results for the thinner cane sample. These graphs show the effect of the cane diameter and trash level on the attenuation experienced by the signal. It should also be noted that the antenna used in the C-band (3.3-4.9GHz, Figures 2.10 (b),(e) and (h)) measurements was more directive (Gain = 18dB) than those employed in the other two bands ; S-Band antenna gain : 10dB and X-Band antenna gain : 16.4dB.[2]

The main conclusions drawn from the experimental measurements and the predicted results where;

- The lower the test signal frequency, the “smoother” the expected response. The probable reason for this observation is that the lower frequency signals are less sensitive to multi-path interference caused by signals taking different routes through the cane. From this point of view then, the lower frequency signals seem to have an advantage.

- Comparing the first and last columns of the experimental measurement figures, it will be seen that the cane attenuates the higher frequency signals more. This is most clearly seen when comparing the measured attenuation at the maximum height above ground. For example, comparing the results for the green cane (rows 2 and 3), the highest frequency range test signals show an attenuation of between 10 and 15dB at the maximum measurement height. In comparison, the lowest frequency test signals exhibit less than 5dB attenuation at the same height. The cane therefore appears to effect much less the lower frequency signal, again pointing to this range as being the preferred choice for a ground detection system.

- Another parameter of interest at this stage was the effect of antenna directivity on the sensor operation. The effect of antenna directivity can be best gauged by comparing the experimental results in columns 1 and 2. The results in these two columns were for overlapping frequency bands but were taken with antennas having quite different gains. The antenna used for the measurements shown in column 1 had a gain of 10.1dB while the antenna employed to obtain the results shown in the middle column was much more directional with a gain of 18dB. The third, X-band antenna had a gain of 16.4dB. Comparing the first two columns then, it can be surmised that the highly directional antenna is less sensitive to the ground level. This result is understandable when it is recalled that the antennas were always operated above ground level during these tests. Under such conditions, only a small fraction of the beam from a directional antenna will contact the ground and so less attenuation would be expected. This result indicates a low gain antenna will be better suited to the proposed measurement application.

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[2] The sharp “peaks” in the measured results are “bad points” and were later found to be due to a intermittent cable assembly.

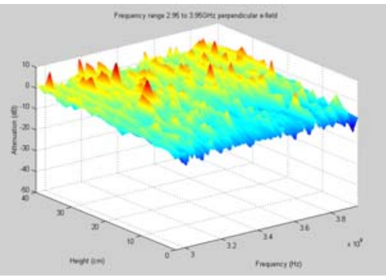

Figure 2.10(a)

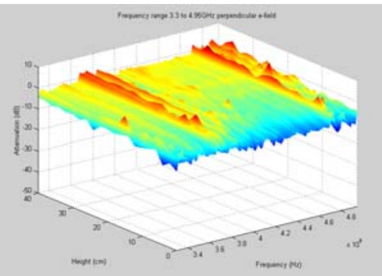

Figure 2.10(b)

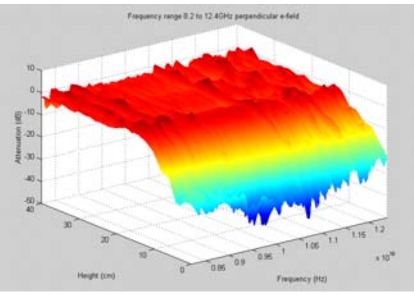

Figure 2.10(c)

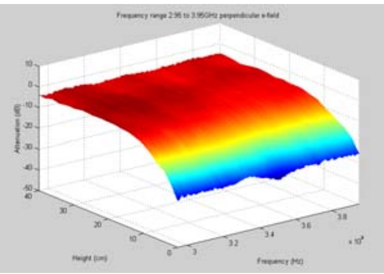

Figure 2.10(d)

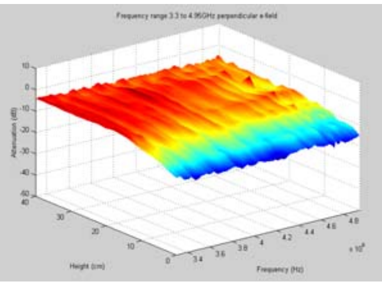

Figure 2.10(e)

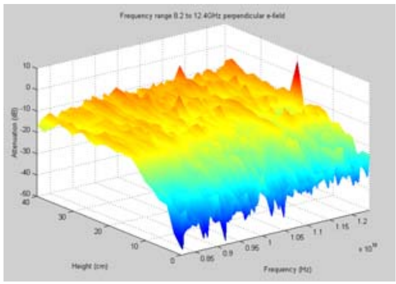

Figure 2.10(f)

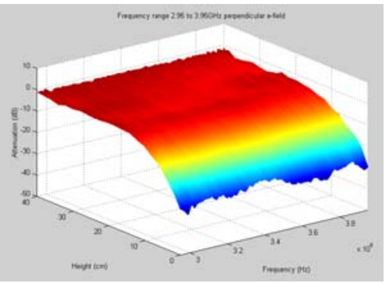

Figure 2.10(g)

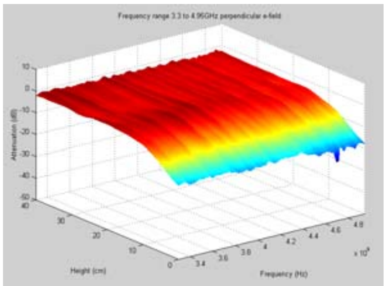

Figure 2.10(h)

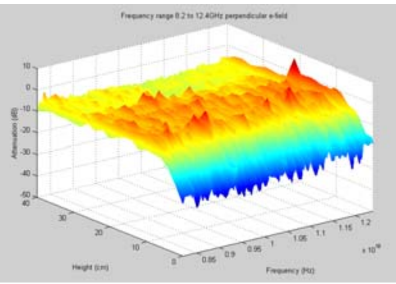

Figure 2.10(i)

The results of the experiments, summarised above, suggest the ground detection sensor should be designed to operate at as low a frequency as is physically possible. It was also shown that the antennas used for the sensor should have reasonably low gain, about 10dB being optimum and should be designed for horizontal polarisation.

2.3 Conclusion

This section examined simulation and laboratory results for the measurement technique proposed to make ground level measurements on board the harvester. The theoretical and laboratory results both seem to indicate that the technique is basically sound. That is, the sensor will respond to the height of the ground but is fairly insensitive to the presence of the cane. The following chapters of this report describe the practical measurements made with prototype sensors both in the field and on-board a cane harvester.

Chapter
3 Field Testing

3.0 Introduction

The laboratory testing outlined in the previous chapter verified the operating principle of the proposed microwave ground detection sensor and helped define the main parameters of a device suitable for use on a cane-harvester. However, it was evident that the environment in a real cane field could be significantly different to the test conditions that could be established in the laboratory. For this reason it was decided to perform tests in "in the field" using an experimental set-up. The purpose of these tests was mainly to establish the effects of the cane and other obstructions on the operation of the transmission sensor.

3.1 Field Test System

To test the proposed measurement technique in the field a special test rig was built. The block diagram of the system developed is shown in Figure 3.1.

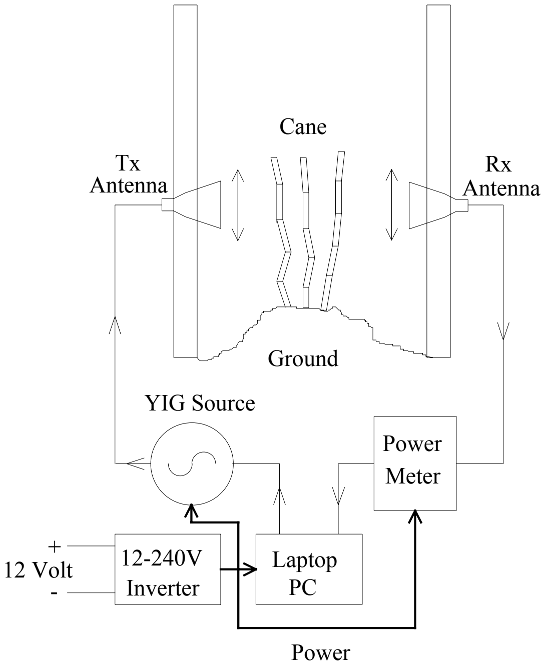

Figure 3.1

As can be seen in Figure 3.1, the test system uses two horn antennas positioned on either side of the row of cane. Each antenna has a gain of about 10dB. During testing the antenna heights were adjusted up or down using motorized screw threads. This arrangement allowed the signal amplitude to be measured at various heights above ground level. The whole rig was made to be transportable so tests could be performed at different points along a row of cane.

The measurement equipment basically comprises a microwave transmitter and receiver section. A YIG source produces the 2.6-3.4 GHz signal that is then radiated by the transmitting antenna. A second horn antenna captures signals propagating to the other side of the cane row. The amplitude of the received signal is measured using an Anritsu microwave power meter. A laptop PC controls the

YIG operating frequency and reads the amplitude of the signal received at the power meter. A Visual Basic program was developed to control the measurement system and log results. Since the whole system needed to be used in the field, it was decided to power the system from a 12 volt car battery, which could then be recharged from a conventional motor vehicle alternator. A 12 volt dc to 240 volt ac inverter was used to convert the 12V supply to the proper form for the power meter and the laptop. The YIG source, power meter, inverter and 12 volt battery were all housed in a metal box for protection during testing. Some photographs of the equipment set up outside the Electrical Engineering Building at James Cook University, are shown in Figures 3.2 and 3.3.

Figure 3.2

Figure 3.3

After logging readings on the laptop PC, graphs of the measurement results were produced using Matlab scripts. The 3 dimensional plots shown in Figures 3.4-3.13 summarise some of the measurements made. The figures included show attenuation versus height above ground (zero level corresponds to the top of the root mound) and over the frequency range 2.6 to 3.4GHz. Measurements were taken at 2cm intervals from 0 to 70cm above ground level. Below each 3-dimensional graph is a second plot that shows the average attenuation over the whole frequency sweep versus height, for heights of less than 50cm. These plots show results from a series of 10 tests performed on a farm in the Herbert District at Trebone over 3 separate days. Data for Figures 3.4-3.11 was collected on the 13th and 14th November, 2000 while the data displayed in Figures 3.12 and 3.13 was obtained on the 17th November, 2000. The weather during this period was quite bad and significant rain fell while undertaking these experiments. During the tests on the 17th November, Figures 3.12 and 3.13, the cane was clumped together and pushed over to simulate the orientation of cane just in front of the base-cutter on a harvester.

Some comments concerning these results are provided below;

- Most graphs show the same "general shape" as those obtained in the laboratory tests and in the electromagnetic field simulations. Well above ground level the attenuation is reasonably constant, giving a "flat" look to the surface. As the antennas approache ground level though, the attenuation increases rapidly. Figures 3.12 and 3.13 show good examples.

- Occasionally responses are almost flat (Figure 3.5) while others show a cyclic variation (Figure 3.11). It is possible that these responses are just bad readings as some equipment calibration problems were experienced during these tests. However, these results could also be caused by the random orientation of the cane during this sort of test. Such results indicated that some averaging or filtering of random measurements might be required in the final implementation.

- Laboratory measurements suggested that the "knee" in the averaged response curve could be used as a reference point in establishing the ground height with respect to the antenna array. However, the field measurements shown here indicate that there is likely to be some variation in this point and again some average may be needed to get consistent results.

- The knee points in tests corresponding to Figures 3.5-3.11 occur at heights of between about 20 and 30cm above ground while in Figures 3.12 and 3.13 the knee occurs at about 32 to 35cm in height. The higher than average knee heights in Figures 3.12 and 3.13 are probably due to the measurement conditions involved. It should be remembered that the cane was "free standing" in the first tests but was clumped together and pushed over (to simulate conditions just in front of the base-cutter) when the last measurements were recorded. As might be expected, it appears the sensor cannot distinguish between the ground and a solid mass of cane. Therefore, since the cane was tightly packed and lying on the ground in the latter case, the knee point appears higher with respect to the real ground level.

Based of these results the following observations/ recommendations were made;

- Tightly packed cane appears the same as solid ground to the sensor and therefore the positioning of the sensor on the harvester will need to be considered carefully so as to best measure the required parameter.

- To measure the full height profile instantaneously, an array of antennas set at different heights that can be individually switched to a common receiver, will need to be developed.

- Some filtering or averaging of results will need to be implemented to reject random fluctuations due to the random orientation of the cane.

- The current field test system is slow to use and does not provide a continuous set of results along the full length of the cane row. Further tests should be made with the antenna array sensor mounted on a movable vehicle.

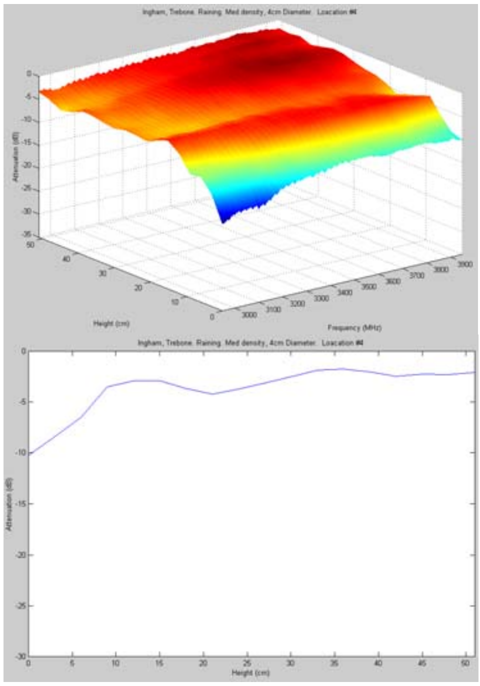

Figure 3.4

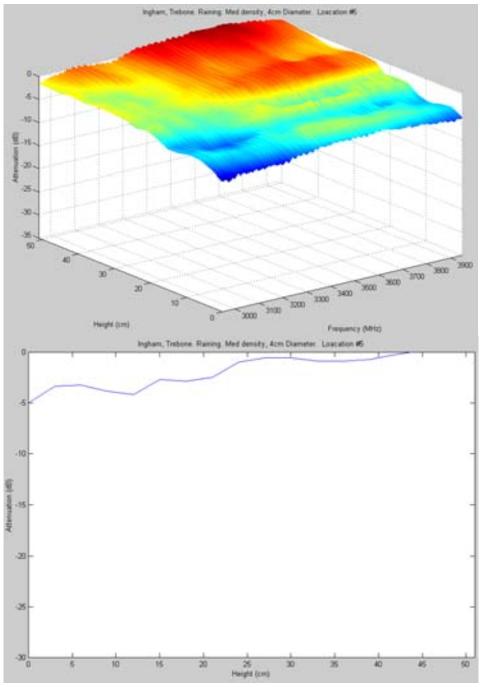

Figure 3.5

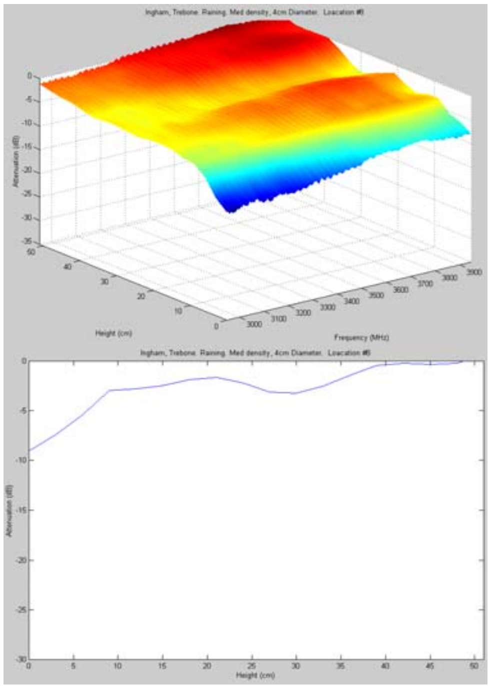

Figure 3.6

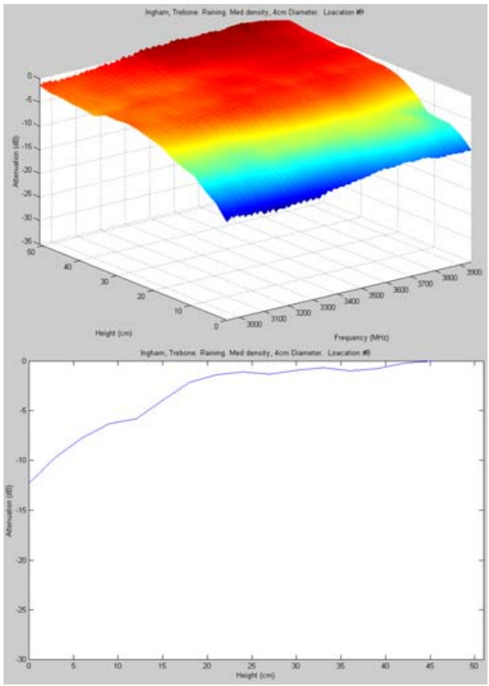

Figure 3.7

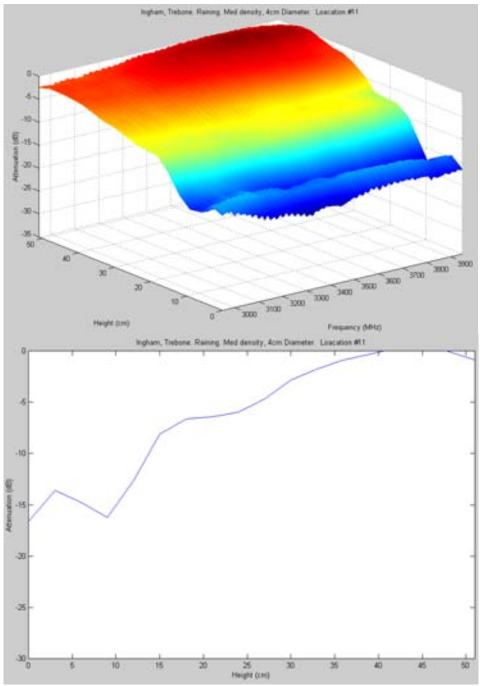

Figure 3.8

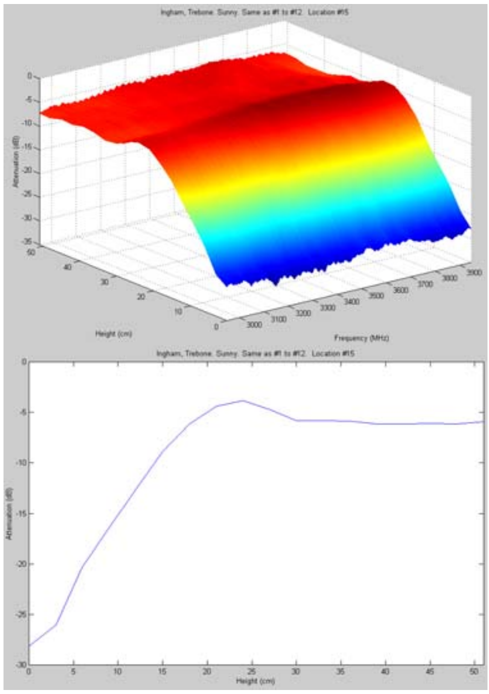

Figure 3.10

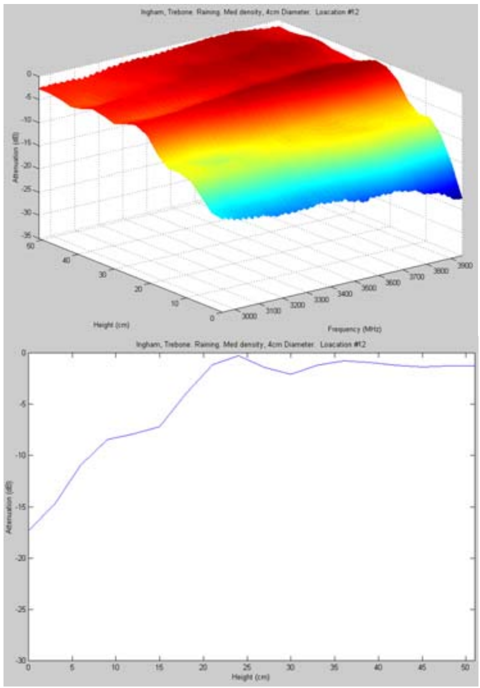

Figure 3.9

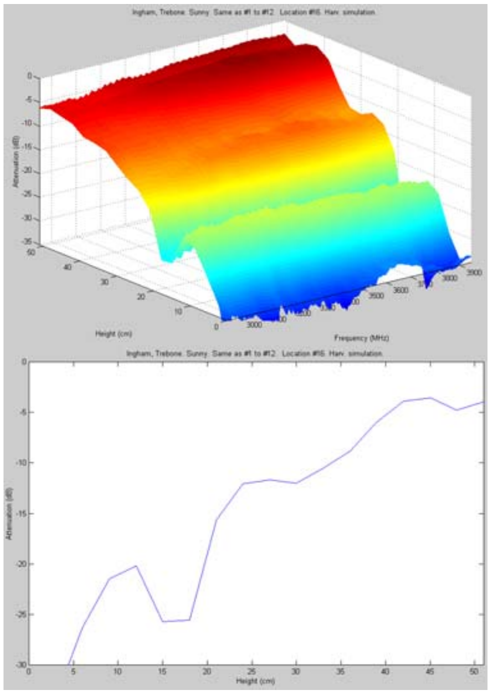

Figure 3.11

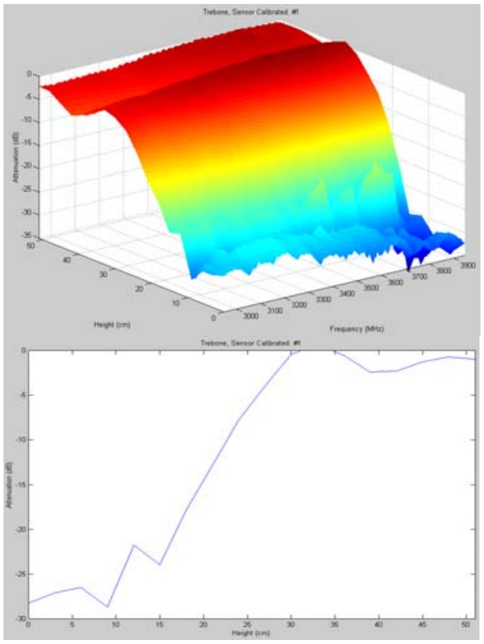

Figure 3.12

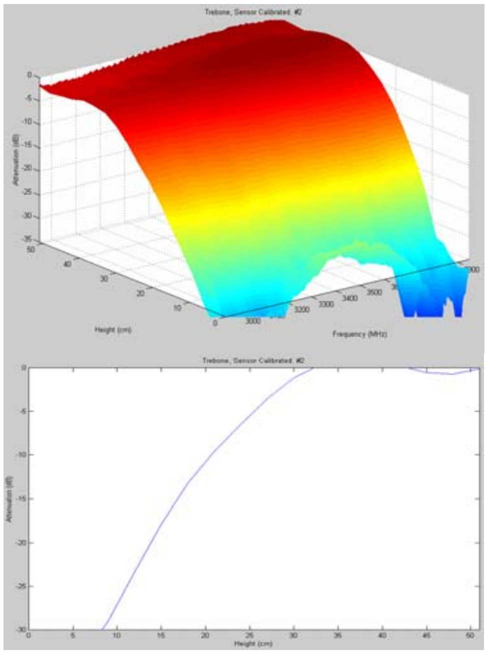

Figure 3.13

3.2 Conclusions

The field measurements described in this Chapter were interesting in that they showed the cane does have a significant effect on the proposed ground detection sensor. As might be expected in a real situation where the cane stalks are almost randomly orientated between the transmitter and receiver, the attenuation profile will not always follow a smooth well-defined shape. However, it could also be argued that if the effect of the cane is random, then averaging of reads taken at different points along the row should remove these variations leaving the desired trend. Fortunately, in the cane harvester application, averaging should be possible by taking many profiles as the cane harvester moves along the row.

Another conclusion of this stage was that the “fixed” test rig built for this project was not suitable to measure multiple profiles along a row in order to take advantage of the averaging described above. To overcome this problem in future work, it is suggested that the test system be mounted on a movable platform. Some preliminary work was undertaken to mount a prototype sensor on a high clearance tractor in order to perform this type of test. Unfortunately, this system could not be completed within the time frame of this project and no tests results are therefore available.

Chapter 4

Prototype Ground Detection Sensor

4.0 Introduction

The success of the laboratory and field experiments suggested it would be useful to build a prototype ground detection sensor for testing on board a cane harvester. The preliminary work had also identified the main specifications and features needed for this type of sensor. This Chapter describes the design of the ground detection sensor built for this task.

4.1 Prototype Ground Detection Sensor Design

The work undertaken previously suggested that the best method of detecting ground level with a microwave sensor is to determine the whole height profile at once and then look at changes in the "knee point" in this response. To achieve this the sensor configuration shown in Figure 4.1 was proposed. Basically this design consists of a transmitter on one side of the cane row and a multi-element receiver array on the other side. The elements of the receiver array can be individually switched to the amplitude detector so the field amplitude at different heights can be measured.

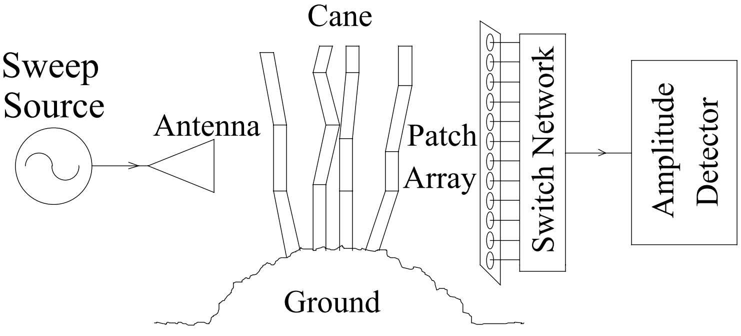

Figure 4.1 : Array Ground Detection Sensor

Based on the proposed configuration, the system shown in Figure 4.2 was built.

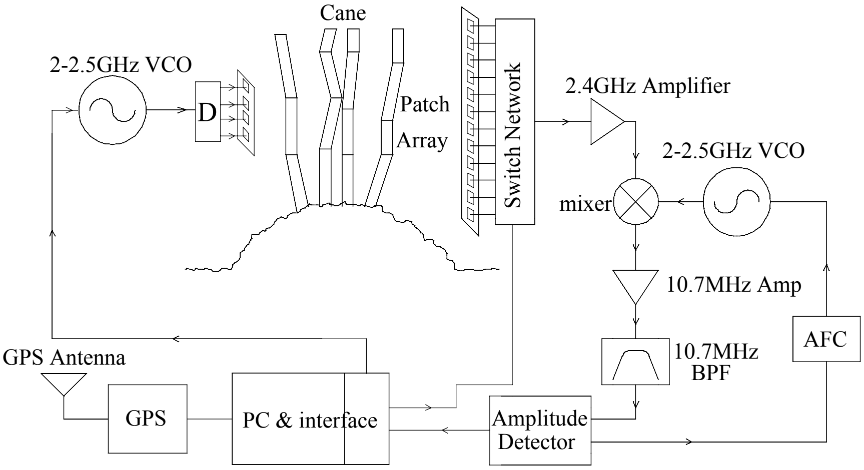

Figure 4.2 : Block diagram of microwave ground detection sensor.

The new sensor transmits a signal of about 2.5GHz from one side of the row of cane to the other. The transmit side antenna consists of a 4-element array of rectangular patch antennas that are driven “in-phase” from a 4 way power divider. This array configuration provides a “broadside” radiation pattern and a gain of about 10dB. The antenna radiation pattern was designed to provide roughly equal signal levels over the full length of the receiver array on the other side of the cane row.

The receiver side of the new sensor again consists of an array of rectangular patch antennas. Twelve antennas spaced over a length of roughly 600 mm are used in the receiver array. The same antenna design as that used in the transmitter array was employed. However, on the receiver side, only one patch antenna at a time is used to measure the incident signal level at a specific height. The required element is selected using computer control via a switching network attached to each of the 12-receiver antennas. This configuration was employed so that the amplitude profile over the full length of the array can be obtained by quickly cycling through all 12 elements of the receiver.

All the rectangular patch antennas employed in the ground detection sensor used a conventional edge fed arrangement [18] that was matched to 50ohms. The elements were manufactured on thick, low dielectric constant substrate ($\varepsilon_r = 4.5$, h = 6.4mm) in order to provide a usable bandwidth of about 120MHz. A wide bandwidth antenna design was chosen to provide some tolerance to frequency inaccuracies in the rest of the system as well as to allow a frequency scanning capability should this be found necessary. The low profile patch antenna configuration was also idea for mounting flush along the inside walls of the cane harvester row dividers.

The rest of the ground detection sensor consists of electronics to generate the 2.5GHz test signal and to measure the amplitude of the received signal. The transmitter stage employs a Minicircuits Voltage Controlled Oscillator (VCO) IC while the amplitude detector is based on a conventional heterodyne radio receiver circuit. The actual amplitude detection is achieved using a Motorola MC13055 FM receiver IC. This device features an analogue voltage output proportional to the input signal level and interfacing circuitry that allows the receiver to be frequency locked to the incoming signal. Tests showed this receiver had a dynamic range of about 30-40dB with a typical amplitude accuracy of about ±2dB. In operation, each channel of the receiver was calibrated to account for the different losses in the antennas, switching network and cables. A typical calibration curve for one channel of the sensor is shown in Figure 4.3.

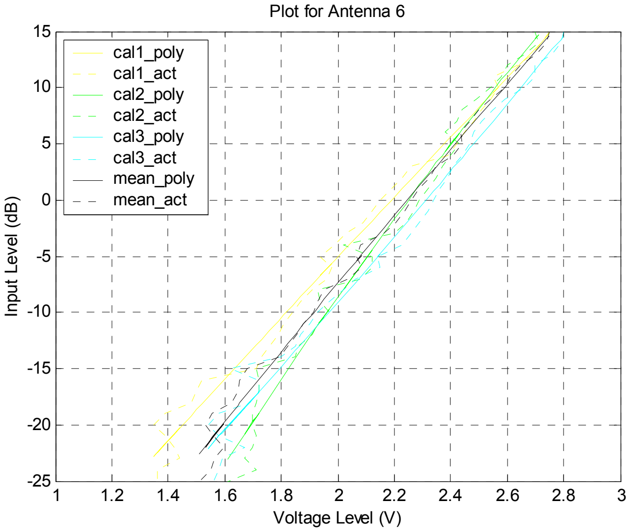

Figure 4.3 : Receiver calibration curve.

The operation of the whole system is coordinated using a laptop PC. The PC can automatically set the transmit frequency, select the desired receiver element and read the measured amplitude of the incident signal. During initial testing the received signal amplitudes were simply stored on disk for later analysis off-line. In addition to measuring amplitude profiles, during testing the PC was also connected to a Global Positioning System (GPS) receiver so as to allow logging of the position and speed of the harvester when measurements were being taken. The equipment was powered directly from the harvester’s 24V dc electrical supply.

Most of the electronics used in this system is quite low cost. The most expensive components are the microwave switches used to select the different receiver array elements. The four packaged, commercial switches used in the prototype circuit had a total cost of about $800. However, these components could be replaced with lower cost (and smaller) alternatives in a final design. Even including the switches though, the component cost of the detector was estimated to be less than $1000. The cost of a sensor installed on a harvester would include additional parts like a micro-controller, cabling etc, but even so, the component cost of a complete system is expected to be less than $2000.

4.2 Detector Testing Results

Initially the sensor system described in section 4.2 was tested under controlled conditions to gauge its response. During these tests, bags of soil were placed between the transmitter and receiver arrays to simulate different ground heights. Typical results from this test are shown in Figure 4.4. The 2 profiles shown were recorded for ground heights of 0cms and 12cms above the lowest receiver array element. The results shown in Figure 4.4 are very simular to the predicted response plotted in Figure 2.6. The measured amplitude profiles do show some irregular variations but the general trend is to receive smaller signal levels on the antenna elements closest the ground. Moreover, the higher the ground level, the more the signals are attenuated by the ground and hence the lower the signal levels recorded will be. A higher ground level also means that elements further up the array will be subject to some degree of blockage. Importantly, these measurements showed that by continuously measuring the amplitude profile over the receiver array, changes in the ground level can be detected.

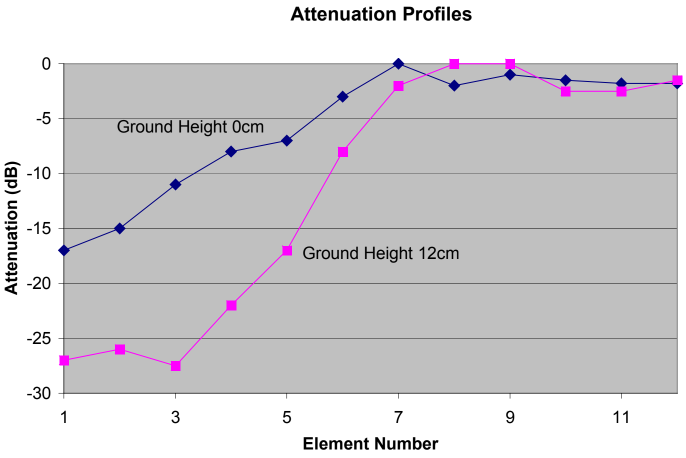

Figure 4.4 : Sensor response under controlled conditions.

4.2 Installation on Harvester

During testing on a harvester, the transmitter and receiver antennas where mounted flush against the inside of the row dividers walls. In the trial work done for this project, the antennas where left bare with a slightly raised metal deflector shield welded in front of the patches to deflect cane over the top of the antennas. Although the antennas did not sustain any major damage during the course of testing for this project, in a commercial installation, the antenna face could be coated with fibreglass or a similar product to reduce the chance of mechanical damage from the cane. A picture of the antennas mounted on an Austoft harvester is shown in Figure 4.3. This figure actually shows three shots of the sensor viewed from the front of the harvester from different angles.

A concern when mounting the sensor on the row divider walls was that the row dividers are raised and lowered independently of the base-cutter. In the base-cutter control situation, this would be a problem since the detector measures ground height with respect to the receiver array and moving the row dividers will therefore produce the same sort of response as a change in ground level. During the preliminary testing undertaken in this project, this mounting location was considered satisfactory to at least test the sensing principle. If the sensor is to be tested when controlling the base-cutter, alternative mounting arrangements will be necessary. One option would be to mount the sensor from the chassis of the harvester, so it doesn't move with the row dividers. The practicalities of such a mounting arrangement have not been studied in detail. However, some potential problems that immediately come to mind including problems having to cut slots in the row dividers to incorporate the mounting brackets, concerns about fouling by cane or trash, strength problems and interference to the row divider movement mechanism inside the row divider cavity.

Another alternative that may be more practical would be to include an auxiliary sensor to measure the position of the row dividers. This measurement could then be employed to compensate the ground height measurements from the antennas mounted directly to the row divider walls.

Figure 4.3 : Picture showing ground detection sensor mounted on the inside of the Austoft harvester row dividers.

Chapter 5 Harvester Testing

5.0 Introduction

To test the sensors suitability for use on-board a cane harvester, tests were performed with the new sensor mounted on a cane harvester while engaged in normal harvesting operations. The primary objective of this test was to see if the sensor did in fact respond to the ground height as needed for this application. However, this test also had a more fundamental aim in checking whether the sensor would actually work in and survive the harsh conditions on-board a harvester.

5.1 Harvester Trial

The sensor described in Chapter 4 was attached to the Austoft Pty. Ltd. research and development harvester in Bundaberg and was trialed during the period 24th – 28th of September, 2001. During these tests the harvester was used to cut various varieties of green cane planted "dual-row". The varieties cut during the trial period, including types Q170, Q151, Q141, Q138 and Q124.

Some general observations from this trial are included below:

1. Strong signals were recorded at the receiver while harvesting. This indicated that the 2.5 GHz radio signal was penetrating the cane in the throat of the harvester and was therefore suitable for this application.

2. The system was operated for about a week without any major problems. Positioning the antennas on the inside of the row divider walls meant there was very little build up of dirt apart from a slight coating on the lower couple of elements. Surprisingly, given their exposed location, mechanical damage to the antennas was also minor consisting mainly of slight scratching of the surface. It should be noted that metal guards were installed in front of the antennas to protect them from the cane entering the row dividers. Generally, it seemed that any dirt and scratching of the antennas caused minimal change to the logged signal levels.

3. During testing, the location and speed of the harvester was logged along with the received signal levels. The purpose of recording the location of the harvester was to allow later inspection of the field to compare the cutting height with the data recorded by the ground detection sensor. Unfortunately, in practice it proved difficult to correlate the measured GPS position data with the actual harvesting position in the field. The 10-meter accuracy of the GPS data was not sufficient to accurately pinpoint a particular location along the row. Furthermore, since the cane was cut green, the blanket of trash coverage left on the ground after harvesting made it very difficult to judge if the base-cutter was operating too high or low. The usefulness of the position data was therefore very limited.

4. No independent measurement of the ground height was possible to compare the actual ground level under the harvester with the measured data. This meant it was impossible to determine the accuracy of the instrument from this type of test. A further complication that was noted earlier was, the row-dividers can be moved independently of each other and the ground. This meant that the sensor should respond similarly to a change in ground height or an adjustment of the row divider settings. Again, this means this test did not allow the sensors response to be directly compared with the ground height under the harvester.

Given the obvious shortcomings of the harvester testing identified above, the data collected was processed to observe the operation of the sensor. An example of a typical sequence of amplitude measurements made on one channel of the receiver as it transversed the paddock is shown in Figure 5.1. It is clearly seen from this figure that the raw data measurements contain a significant "noise" component. As was noted during the field simulations and the field-testing using the test rig, random fluctuations in the measured signal levels are expected due to the random influence of the cane. It was therefore decided to filter or smooth the raw data in order to better observe the underlying trends. The effects of different filtering schemes when applied to the raw data are shown in Figure 5.1 by dashed curves. Note that smoothing had the desired effect of removing the random variations but retaining the important underlying trends. The Type II filter was eventually chosen to filter the final data.

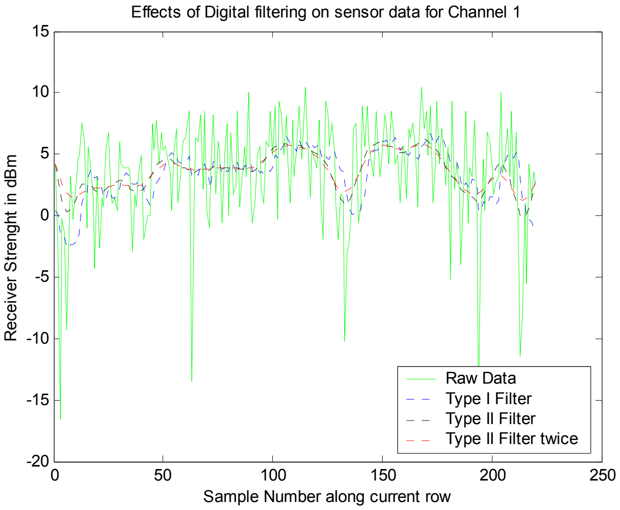

Figure 5.1 : The effects of Digital Filtering to smooth the sensor data

After smoothing the raw data, it was possible to compare the responses on a number of channels, at the same time. Figure 5.2 shows a typical trend of all twelve receive antennas levels as they varied along a row during harvesting. Channel 1 is the lowest antenna while channel 12 is the highest. Note the various curves have been filtered to remove random variations. The different curves have also been averaged and offset by 5dB to aid clarity when comparing the different responses. It can be seen that the shapes of these graphs all tend to be similar indicating that changes in density along the row does have a similar effect on all the signals. However, if the graphs are studied closely it will also be seen that there are some instances where a change in signal level is noticed on the lower channels but is less obvious on the higher ones. One such event is seen at around sample 205 in Figure 5.2. It seems probable that this case occurs when there is a change in the ground level causing a change in level on the lowest antennas only. Importantly, these results tend to suggest that with correct processing of the data it should be possible to use this sensor to detect ground height through cane.

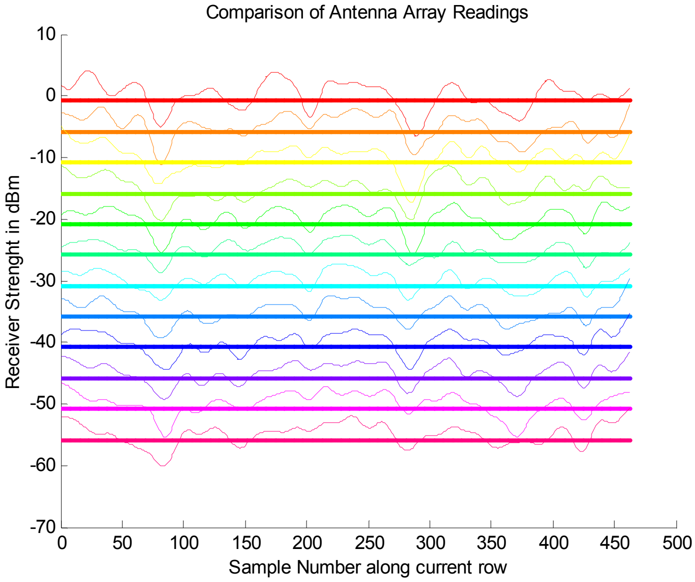

Figure 5.2 : Measured amplitude trends on the different channels of the ground detection sensor receiver

5.2 Conclusions

The testing performed on the microwave ground detection sensor configuration developed during this project shows that this technique is suitable for measuring ground level on a working harvester. Obviously, a device installed permanently on a harvester would need to be ruggedised somewhat compared with the prototype device tested in this work, but the basic principle seems appropriate. Preliminary analysis of the data collected has shown that the sensor and the sensing technique have performed as expected. The results indicate that with proper signal processing, the sensor could be used to measure ground height and could thus be employed to control the base-cutter on a working harvester.

Future work needs to address the problem of being able to have an independent measurement of ground height while the sensor is being operated so as to determine how best to process the raw readings as well as check the accuracy of the technique.

Chapter
6

Conclusion

6.0 Conclusion

This project was successful in achieving what it set out to do, that is, test the suitability of a new, microwave ground detection sensor for use on-board sugar cane harvesters. Initially, laboratory tests and later electromagnetic field simulations where employed to determine if the blockage caused by the ground when a radio signal is sent from one side of the row of cane to the other, could be employed to measure the ground level. Both simulations and experiments had similar conclusions, basically the closer to the ground that the receiver was positioned, the greater the signal attenuation was expected to be. These tests laid the foundations for this project establishing not only the basic sensing technique but also the preferred operating frequency, signal polarisation and antenna gain. Experimental testing in the field extended on this work and showed that to remove the influence of cane density on the measurements, an amplitude profile measurement rather than a spot sample would be needed. Apparatus to make this type of measurement was then developed. The prototype built used low profile patch antenna arrays for both the transmitter and receiver antennas. These antennas proved idea to mount on the inside of the row divider walls of a harvester. The receiver array incorporated a switching network that allowed individual elements of the receiver array to be connected to the amplitude detection electronics. By thus scanning over the length of the receiver array, a received signal amplitude profile versus height could be obtained. Dedicated electronic circuits were built to generate and detect the radio signals required by the sensor. A laptop computer completed the design providing control and data logging facilities.

Finally, the prototype sensor developed was fitted to a harvester and tested in an actual harvesting situation. While the interpretation of the results obtained during these tests were hampered by the problem of not having an independent measure of the ground height, the trial did provide valuable information on the proposed sensors operation. Of primary importance, the sensor did survive the harsh conditions on-board the harvester and did work as expected. After proper processing the measured results also looked very promising. At times, the lower elements in the receiver array measured a lower signal level than the higher antennas and seemed to show the sensor responding to the ground level as required.

The estimated cost of the prototype sensor installed on a harvester would be less than $2000 AUD. However, with economies of scale and some redesign, the cost of a commercial sensor installed on a harvester would probably be much less than this amount, possibly less than $1000 AUD.

6.1 Future Work

This project did successfully lay the foundations for the microwave ground detection sensor. However, further work will be required to get this device to the stage where it can be used to control the base cutter on a harvester and could then be developed into a commercial product.

To control the harvester base cutter it will be essential to know the capabilities of the ground level sensor if this control system is to be designed properly. For example, it will be necessary to know the accuracy and response speed of the sensor in order to determine over what time frame the readings need to be averaged before the base cutter setting should be adjusted. To provide this type of information it will be necessary to perform further field testing with this sensor. This testing should ideally be performed with the sensor mounted on a high clearance tractor. Use of a tractor rather than a cane harvester will be an advantage in this case as the ground height can be measured next to the cane so a direct comparison can be done with the sensor response. Furthermore, a high clearance tractor allows greater flexibility when performing measurements since a tractor can be sped up or slowed down even stopped altogether. Using a tractor, would also allow the same measurement to be repeated a number of times to study the repeatability of the sensor.

Work towards field-testing on a high clearance tractor was started during this project. Initially, it was planned to do high clearance tractor tests during this project through Irving Farm Services in Ingham. A mount to attach the sensor to the hydraulic rams on the back of a high clearance tractor was built and some time was spent learning how to operate this machinery. Eventually though, the time constraints imposed by this project and the need to do harvester testing, meant no tests were able to be performed.

Once the dynamic operational characteristics of the ground detection sensor are known, the next stage in this project would be to attach the sensor to a harvester and use it to control the base-cutter height. Using this type of test it would then be possible to compare the amount of extraneous matter collected with or without the sensor being used to control the base-cutter height. As this type of testing may involve modification to the harvester, this work would be best done in conjunction with a commercial harvester manufacturer like Case/ Austoft.

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List of Publications

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Page, R.L. “Ground detection radar using microwave technology” Bachelor of Engineering Thesis in Electrical and Electronic Engineering, School of Engineering, James Cook University, 1999.

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Page, R.L. and Woods, G.S. “Sensing of Ground Level through Sugar Cane using Microwave Techniques”, *Workshop on Applications of Radio Science (WARS’00)*, La Trobe University, 27-29 April, 2000.

Woods, G.S., Maskell, D.L. and Ruxton, A. “Microwave Ground Level Detection Sensor” 1999 Asia Pacific Microwave Conference, Singapore, 30 November - 3 December 1999, pp.531-534.

Woods, G.S., Page, R.L. and Maskell, D.L. “Ground Height Detection Sensor for Control of Harvesting Equipment” To be presented at the Asia Pacific Microwave Conference, November 19-22, 2002.

Seminar Presentation

Woods, G.S. and Page, R.L. “Automated basecutter height control” JCU Sugar Technology 2000, Conference 8th November 2000.

An electronic copy of these papers have been included with the electronic version of this report.