

# Sensing of Ground Level through Sugar Cane using Microwave Techniques

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## I. Abstract

Automatic control systems have the ability to greatly improve modern agriculture, [1], by increasing efficiency, allowing greater precision, and by decreasing the associated costs. Sugar cane harvesting is one activity that has a need for such systems. In particular, control of the harvester's "base-cutter" height can greatly improve the harvesting efficiency and reduce the amount of extraneous matter reaching the mill.

This paper investigates the feasibility of an electronic sensor, based on microwave technology, to accurately sense ground level and hence control the harvester base-cutter. The microwave sensing technique studied uses a transmission style sensor that measures the amplitude of an electromagnetic wave propagating from one side of the row of cane to the other. Results show that an operating frequency between 2 and 4 GHz, transmitted using a 9.5dB gain antenna, is best suited to this application.

## II. Introduction

Mechanised harvesters are used extensively for harvesting sugar cane crops and employ a "base-cutter" to cut the stalk at, or just below, ground level. Unfortunately, due to the position of the harvester cabin it is impossible for the operator to see where the base-cutter is actually cutting during operation, the result is that optimum height control is seldom manually achieved in practice. Moreover, the operator is unable to make the numerous small height adjustments that are necessary to maintain the desired base-cutter height whilst the harvester is traversing uneven terrain. Improper adjustment of the base-cutter height during harvesting has a number of adverse effects on both the sugar cane plant, and on the quality and quantity of sugar cane collected. The implications due to inaccurate base-cutter height control are the following: -

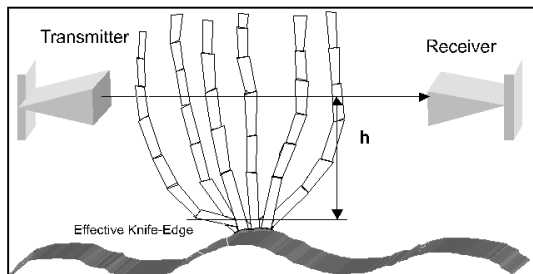
- Cutting the sugar cane plant too high above ground level reduces productivity, while increasing the risk of disease entering the plant due to the possibility of shattered cane stalks.
- Cutting the sugar cane plant too low can introduce extra soil into the refining stages of the sugar mill causing additional maintenance costs, while also increasing the risk of permanent damage to the cane plant roots.

The latter scenario, that of cutting the plant below ground level, is common practise amongst harvester operators. The worst effect of the harvester cutting the plant below ground level is the increased milling cost due to the excess soil entering the factory with the cane. Since the amount of soil present can vary in excess of 3.5% of the gross weight of sugar cane harvested, this represents a major cost to the milling sector.

The problems associated with inaccurate base-cutter height adjustment on sugar cane harvesters suggests a sensor that could detect ground level and therefore be employed to automatically adjust the base-cutter level, would be very useful. Various sensors have been proposed for this application in the past. These sensors range from mechanical sensors using wheels or skids [2] to ultrasonic level detectors [3]. Unfortunately, previous sensing techniques have had limited success for this application, mainly due to the harsh environment and operating conditions involved. Mechanical sensors are prone to fouling from trash and mud, while ultrasonic sensors become “confused” due to obstructions such as leaves and dust. The inherent problems of traditional measurement techniques have prompted work on a microwave type sensor for this task. Microwaves can easily penetrate dust, smoke and moderate amounts of vegetation without significant signal attenuation and therefore should be less susceptible to the problems encountered by other types of devices. The microwave sensors used for the harvester application would be non-contact and thus will not suffer from fouling due to mud or trash. Some work has already been reported on a dual-frequency, continuous-wave radar sensor system [4] for this application. However, the results presented from this study were all laboratory based and were not conclusive. This paper details the preliminary results of a new study to design a microwave sensor capable of detecting ground level through sugar cane plants.

### III. Sensor Test Configuration

The sensor configuration investigated was as shown in Fig. 1. In the required harvester application the antennas would be attached to the stationary “row dividers” of the harvester. When the cutting height is adjusted the base-cutter moves with the row dividers. The proposed measurement technique was based on the assumption that as the height from the ground level to the antennas varies, the amplitude of the received signal should vary predictably providing a means of judging ground height.



**Figure 1: Diagram of the transmission style detection system investigated**

The aim of this study was to test this approach and determine the optimum choice of signal frequency and antenna gain for this application. Frequencies in the S-band (2.6-3.95 GHz), C-band (3.3-4.95 GHz), and X-band (8.2-12.4 GHz) were examined. The frequency ranges tested were a compromise between the opposing needs of using low frequencies to obtain good penetration and less sensitivity to obstructions, and the requirement for small, yet reasonable gain antennas. During the measurements a HP 8722A Vector Network Analyser (VNA) was used to record

the relative magnitude of the received signal with respect to the transmitted signal. Prior to measurements the VNA was calibrated to account for the free space insertion loss between the antennas and thus the results only show the effects of the ground and cane in each of the height measurements. The various signals were tested for their effectiveness under different conditions and for a variety of cane types. The three types of cane tested were burnt, green dense and green sparse. However, only the most interesting of these results are included in this paper.

### IV. Theoretical Simulation Results

To better understand the operation of the proposed ground level sensor it was decided to develop a theoretical propagation model for the measurement system. The purpose of this model was not

to determine the actual attenuation values that should be measured in a field sensor but rather to determine if the attenuation is expected to vary as a result of the presence of the ground and what parameters are likely to effect this response. Initially a very simple model based on the assumption that the cane has no effect on the propagating signal and that the soil mound at the base on the cane can be considered as a “knife-edge conductor” was employed. The signal levels above and below the top of the soil mound were then calculated using knife-edge diffraction theory [4] based on (1).

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

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

Using the simple model described by (1), the predicted signal level variation over the height range of 5cm below the cane stool mound to 10cm above was calculated. The two antennas were taken to be 50cm either side of the cane row. In order to allow comparisons of measurements and theory, the centre frequencies of the three bands investigated in the laboratory tests were employed during this simulation. The results obtained are shown in Fig. 2. These results indicate that the received signal should vary with respect to height as required for this application. Furthermore, the simulation results suggest that the lowest frequency signal should provide the widest possible measurement range. That is, the graph for the S-band frequency range (▲) shows a change in attenuation for up to 7 cm above ground while the other graphs “flatten out” at proportionally lower heights. To verify these results the laboratory measurements described below were conducted.

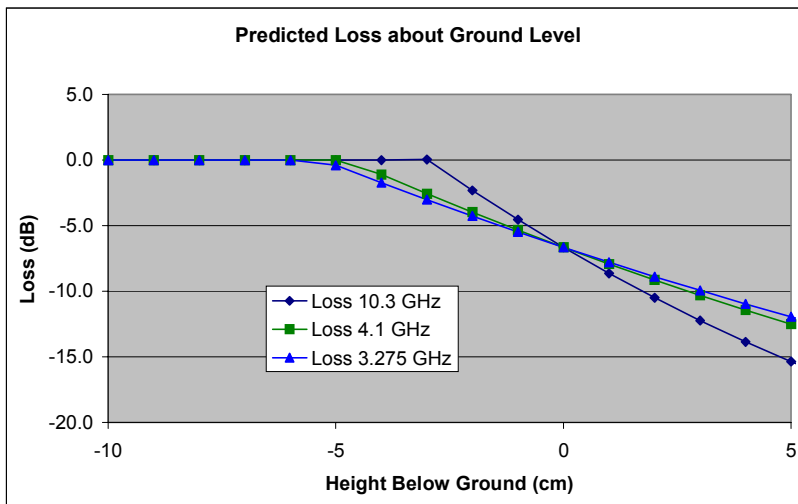


Figure 2 : Simulation results assuming the ground acts as a knife-edge conductor.

While it was obvious that this model would not yield high accuracy, it was decided to employ this crude simulation in order to obtain an appreciation of the dominant processes involved. A more complex model taking into account the actual size and orientation of the antennas, the

ground and even the cane could have been developed but was not considered worth the extra effort. In this situation it is doubtful that the results obtained with any theoretical model will adequately simulate the almost random environment of an actual cane paddock. It is argued therefore that final testing of any sensor configuration must be undertaken in the actual environment of a cane field.

## V. Test Results

To test the suitability of the measurement scheme described in Section III, a continuous row of cane was simulated in the laboratory. The simulated row of cane consisted of 60cm of an actual sugar cane row that had been removed from a typical paddock. The antennas were mounted 50cm on either side of the cane row for testing. Enough cane was used to ensure that the cane was well within the beamwidth of the antennas. The gain at the cane fringe was  $-10\text{dB}$  for the low frequency antenna and  $-22\text{dB}$  for the other two antennas. The test row of cane was positioned on a plastic trolley that could be raised or lowered around the fixed antennas. This assembly allowed the response of the sensor to be measured for different ground heights and frequencies.

The signal attenuation was recorded for three varieties of sugar cane and the three different frequency bands. The graphs included below show a three dimensional view of the amplitude of the received signal versus frequency and the antenna height above ground, for some typical measurements. The plots shown were all for “green cane” samples as this is the most common form of harvested cane nowadays (over 95% of sugar cane is now harvested “green”). Comparing these results to the theoretical curves described in section III it is obvious that both theory and measurements show similar trends. That is, above the top line of the obstacle, small attenuation is experienced, while below this line, the signal strength drops away as the height decreases. This observation suggests that diffraction by the ground is a dominant mechanism by which the transmitted signal is attenuated. Furthermore, as required for this application, these graphs indicate that there is a strong correlation between the received signal amplitude and the antenna height above ground. The signal levels were found to vary by up to  $35\text{dB}$  over a 20cm range above ground level.

As predicted by the simulation, the lowest frequency signal exhibits useable changes in signal level over the largest range above ground. However, a measured result not predicted by the theoretical model is that the middle frequency range, Fig. 4 and 7, has a small measurement range and only shows small changes in amplitude. The suggested explanation for this apparent anomaly was that the C-band antenna has a much higher gain than the S-band antenna ( $22\text{dB}$  compared with  $10\text{dB}$ ) though the frequencies are relatively close (centre frequency of  $3\text{GHz}$  compared with  $4.5\text{GHz}$ ). Practically this observation indicates that the more directional radiation pattern of the high gain antenna interacts with the ground to a lesser degree. The crude propagation model used for the simulation does not account for antenna gain and therefore fails to predict this trend.

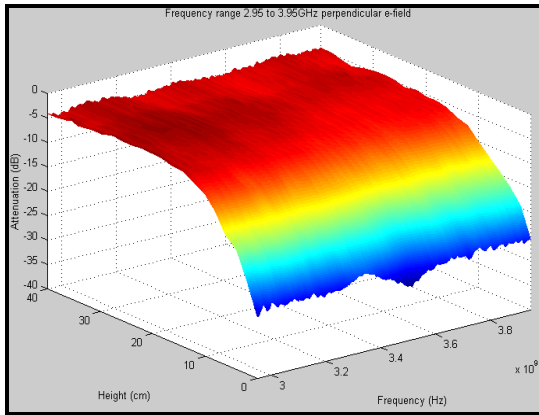


Figure 3: Attenuation Vs Height Vs Frequency Response for Antenna#1 transmitting through Sparse Green Sugar Cane.

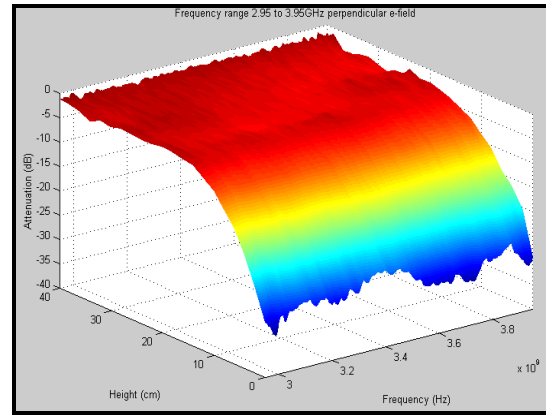


Figure 6: Attenuation Vs Height Vs Frequency Response for Antenna#1 transmitting through Dense Green Sugar Cane.

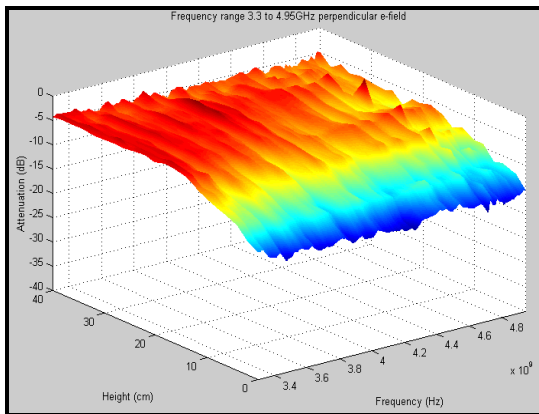


Figure 4: Attenuation Vs Height Vs Frequency Response for Antenna#2 transmitting through Sparse Green Sugar Cane.

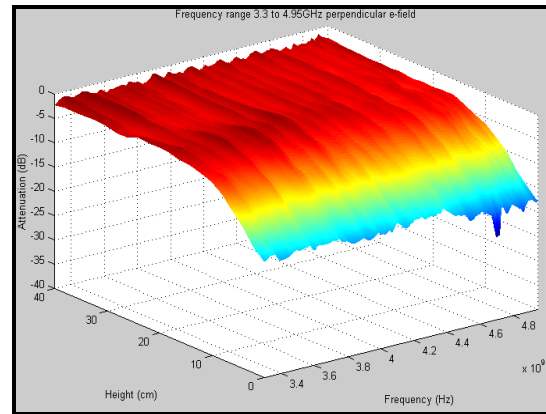


Figure 7: Attenuation Vs Height Vs Frequency Response for Antenna#2 transmitting through Dense Green Sugar Cane.

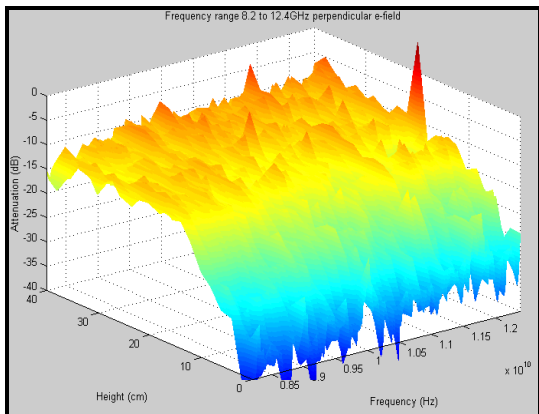


Figure 5: Attenuation Vs Height Vs Frequency Response for Antenna#3 transmitting through Sparse Green Sugar Cane.

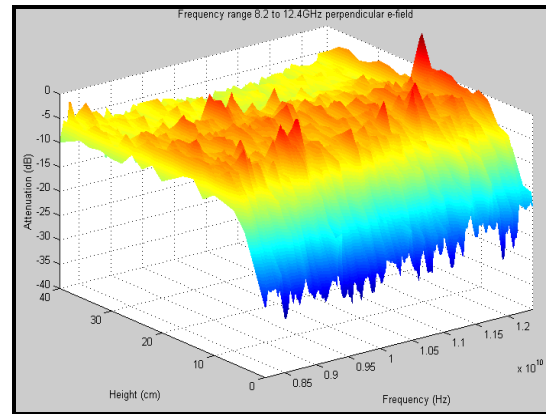


Figure 8: Attenuation Vs Height Vs Frequency Response for Antenna#3 transmitting through Dense Green Sugar Cane.

The actual measurement results show more variability than theoretically predicted. This observation is understandable when it is remembered that the theoretical model does not take into account the effect of the cane stalks. It will also be noted that the actual measured

attenuation at ground level is greater than predicted. This result is probably due to the actual cane mound being “rounded” rather than a “knife-edge” as assumed in the prediction. A rounded obstacle will generally produce less diffraction and therefore cause lower signal levels at ground height. This idea is supported by the results, which show a closer comparison between the measured and predicted attenuation in the lower frequency (2.6-3.95GHz) band where the wavelength is larger and the soil mound will be more accurately represented as a “knife-edge”. Most importantly though, these results indicate that a transmission type sensor based on the 2.6-3.95GHz range would provide the best performance in this instance. This frequency range seemed to give the best sensitivity to ground height and was also the “smoothest” of the three plots indicating low sensitivity to the cane itself.

## **VI Conclusions**

Preliminary results of a study to develop a microwave sensor capable of detecting ground level in the presence of growing sugar cane were provided. It was found that an S-band transmission style sensor configuration provided the greatest sensitivity to the ground level while being the least susceptible to interference produced due to the cane stalks. The tests used a simulated row of cane to show that the signal amplitude decreased as the antennas approached ground level. A very simple theoretical model for this application based on knife-edge diffraction was also investigated. Although the theoretical and measured results are somewhat different, the same overall trends were observed. That the results of the theoretical prediction are quantitatively not in very close agreement with the measured results is not surprising given the crude nature of the chosen propagation model. These differences are of little practical interest though since the probable causes are explainable and even a very elaborate model is unlikely to be accurate given the complexity of a typical cane field. Further work is considered essential to fully justify the use of such a sensing mechanism for commercial practices. It is strongly suggested that the sensor be tested under actual conditions in a cane paddock, which are very random and extremely difficult to reproduce under laboratory conditions. In conclusion, the findings of this paper show some promise that sensors mounted at the correct positions on a sugar cane harvester could produce enough data to provide electronic control of the base cutter.

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