UNIVERSITI PUTRA MALAYSIA

A MICROSTRIP SENSOR FOR DETERMINATION OF HARVESTING TIME FOR OIL PALM FRUITS

ZULKIFLY BIN ABBAS

A MICROSTRIP SENSOR FOR DETERMINATION OF HARVESTING TIME FOR OIL PALM FRUITS

By

ZULKIFLY BIN ABBAS

Thesis Submitted in Fulfilment of the Requirements for the Degree of Master of Science in the Faculty of Science and Environmental Studies,
Universiti Pertanian Malaysia

March 1994

To My Wife and Sons

Ana, Azimi and Faiz

ACKNOWLEDGEMENTS

Many people have helped this thesis in one way or another and I would like to gratefully acknowledge their help and encouragement.

First and foremost I would like to thank the Universiti Pertanian Malaysia, for allowing me to study part-time for the degree of M.S. To the University Farm Office, I would like to extend a thank you for the support throughout this undertaking.

I am deeply indebted to my chairman, Dr. Kaida Khalid for his guidance, advice, encouragement and every possible help throughout this work. I am also no less grateful to my committee members: Dr. Yahya Mat Hassan, Dr. Shahrin Ibrahim and Dr. Zainal Abidin Sulaiman for many helpful comments and suggestions.

To Dr. Azis Ariffin (PORIM), Dr. Sidek Silong and Dr. Zaki, I would like to extend my thanks for their coperation and assistance. Also I wish to thank again Dr. Yahya Mat Hassan, the former Head of Physics Department and Dr. Harun Budin, the former Director of Pusat Sains Asasi for their infectious drive and encouragement, particularly at the early stage of this work. Equally, my special thanks are due to my colleagues for their various contributions. In particular, I would like to express my deepest appreciation to En. Mohd Nor Mokhtar, En. Anuar Ahmad, En. Azizul Azlan and Pn. Khatijah Abd. Jalil for their excellent support and encouragements. I wish especially to thank En.

Roslim, En. Nordin and Cik Marianni for their highly technical assistance in almost every aspect of the project.

Finally, I would like to take this opportunity to thank my family for their patience and understanding that made it possible for me to undertake this work.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure

LIST OF PLATES

Plate

LIST OF SYMBOLS

C	capacitance with dielectric
C_a	capacitance without dielectric
$f(\beta)$	Fourier transform of function f(x)
f	frequency
G	Green's function
V_p	phase velocity
ε_r	relative permittivity
ε_{eff}	microstrip effective dieclectric constant
ε^*	complex permittivity of mixture
ε'	static permittivity
ε''	dielectric loss
ε_o	free-space permittivity
ε_w	complex permittivity of water
ε_ℓ	complex permittivity of oil
ε_f	complex permittivity of fibre
V_w	volume fraction of water
V_ℓ	volume fraction of oil
V_f	volume fraction of fibre
ρ_w	relative density of water
ρ_ℓ	relative density of oil
ρ_f	relative density of fibre
m	relative moisture content
m.c.	moisture content

S_{11}, S_{12}, S_{21}, S_{22}, S'_{11}, S'_{12}, S'_{21}, S'_{22}, S''_{11}, S''_{12}, S''_{21}, S''_{22}	scattering parameters of the two-port network
Z_0	characteristic impedance
Z_a^0	characteristic impedance in air
$\rho(x,y)$	surface charge density
$\rho(\beta)$	Fourier Transform of $\rho(x,y)$
σ	conductivity
q	filling fraction of the dielectric material
α_d	dielectric loss of double-covered microstrip
ω	angular frequency
Ω	ohms
Φ	electrostatic potential
Γ	reflection coefficient
γ	propagation constant
β	phase constant
ℓ_1, ℓ_2	length of transmission lines
w	width of conducting strip
h	substrate thickness
s	thickness of protective layer
d	thickness of the sample

Abstract of thesis submitted to the Senate of Universiti Pertanian Malaysia in fulfilment of the requirements for the degree of Master of Science.

MICROSTRIP SENSOR FOR DETERMINATION OF HARVESTING TIME FOR OIL PALM FRUITS

By

Zulkifly Abbas

March 1994

Chairman : Associate Professor Kaida Khalid, Ph.D.

Faculty : Science and Environmental Studies

The conventional method to determine ripeness of the oil palm bunch is by using the number or percentage of detached fruits per bunch. However, the method has the disadvantage that it does not relate to oil quantity and quality. Previous work has shown a close relationship between oil content and moisture content during fruit development. Thus, the oil content and subsequently the time to harvest the fruit bunch can be determined from moisture measurements.

In this study, a microstrip sensor has been developed to determine the optimum time of harvesting the oil palm fruits based on microwave attenuation. The sensor operating at 10.7 GHz was fabricated using RT-Duroid subtrate and is suitable for single fruit measurements. A theoretical analysis has been carried out to predict the variation in attenuation with moisture content in the fruit mesocarp. The propagation of the electromagnetic wave in the microstrip is based on quasi-transverse electromagnetic mode (TEM mode) and the attenuation is obtained by using signal flow graph technique.

Attenuation measurements have been performed on 83 fruits of *tenera* variety from different 11-year old oil palms using an Automatic Network Analyser. The percentage of moisture content (% mc) and the corresponding attenuation ($|S_{21}|$) of the sensor were monitored at weekly intervals from 12 weeks after anthesis until the fruits were fully ripe. Results show that the optimum time to harvest the fruits can be indicated by the relationship between attenuation, moisture content and oil content with weeks after anthesis. Based on this relationship, the stage of the development of oil palm fruit can be classified into four main categories: under ripe ($|S_{21}|$ above 17 dB), nearly ripe (14 dB to 17 dB), ripe (13 dB to 14 dB) and fully ripe (less than 13 db). A calibration equation has been obtained and it is found that (i) the sensitivity of the sensor is about 0.6 dB/% mc (ii) moisture content for a batch of fruits can be determined with an uncertainty of less than ± 0.2% within 95% confidence limit. Also the results show that the difference between theory and experiment for attenuation in the range of 25% to 85% moisture content is less than 4%.

It is concluded that the microstrip sensor does not only enable the determination of the stages of fruit ripeness but also suitable for assesing the quality of fruits that reach the processing plant. In addition, a single test of the sample is adequate for predicting the optimum time of harvesting by applying the profile of ripeness.

Abstrak tesis yang dikemukakan kepada Senat Universiti Pertanian Malaysia sebagai memenuhi syarat-syarat untuk penganugerahan ijazah Master Sains.

SENSOR MIKROSTRIP UNTUK PENENTUAN MASA MEMETIK BUAH KELAPA SAWIT

oleh

Zulkifly Abbas

Mac 1994

Pengerusi : Professor Madya Kaida Khalid, Ph.D.

Fakulti : Sains dan Alam Sekitar

Kaedah biasa dalam penentuan kematangan buah kelapa sawit ialah dengan menggunakan bilangan atau peratusan buah yang gugur pada sesuatu tandan. Bagaimanapun kaedah ini mempunyai masaalah kerana tidak dapat mengaitkan secara terus dengan kuantiti dan kualiti minyak dalam buah. Kajian menunjukkan bahawa terdapat perkaitan yang rapat antara kuantiti minyak dan kuantiti air di dalam perkembangan buah. Justeru itu dengan menentukan kandungan air di dalam buah ini, kuantiti minyak dan seterusnya masa masak dapat ditentukan.

Dalam kajian ini, suatu sensor kelengasan mikrostrip telah dibina untuk menentukan masa optimum bagi memetik buah kelapa sawit berasaskan pengecilan gelombang mikro. Pengesan ini

beroperasi pada 10.7 GHz, dibina dari substrat RT-Duroid dan sesuai digunakan bagi pengukuran satu biji buah. Suatu penganalisis teori bagi menjangka nilai pengecilan atau kehilangan sisipan terhadap kandungan kelengasan di dalam mesokarp buah telah dijalankan. Perambatan gelombang elektromagnet pada mikrostrip ini berasaskan mod quasi-elektromagnet tegak (TEM-mode) dan nilai pengecilan diperolehi menggunakan teknik aliran isyarat.

Pengukuran pengecilan telah dilakukan keatas 83 biji buah dari jenis *tenera* dari pokok-pokok berumur kira-kira 11 tahun yang berlainan menggunakan Penganalisa Rangkaian Automatik. Peratus kandungan kelengasan (% mc) dan bacaan pengecilan $|S_{21}|$ yang sepadan diukur pada setiap minggu mulai minggu ke 12 selepas pendebungaan sehingga buah-buah matang sepenuhnya. Keputusan-keputusan pengukuran menunjukkan bahawa masa optima untuk memetik buah-buah boleh diperolehi dari hubungan antara pengecilan, kandungan kelengasan dan kandungan minyak dengan minggu selepas pendebungaan. Berdasarkan hubungan ini, pengembangan buah dapat dikelaskan kepada empat kategori: tidak matang ($|S_{21}|$ melebihi 17 dB), hampir matang (14 dB hingga 17 dB), matang (13 dB hingga 14 dB) dan matang sepenuhnya (kurang dari 13 dB). Suatu persamaan tentukuran telah diperolehi dan adalah didapati bahawa (i) kepekaan pengesan adalah lebih kurang 0.6 dB/% mc (ii) kandungan kelengasan untuk sekelompok buah-buah boleh ditentukan dengan ketakpastian kurang dari $\pm$ 0.2% dalam sela keyakinan 95%. Keputusan-keputusan juga menunjukkan bahawa perbezaan antara teori dengan eksperimen untuk pengecilan gelombang dalam julat 25% hingga 85% kelengasan adalah kurang dari 4%.

Sensor mikrostrip ini bukan sahaja dapat menentukan peringkat perkembangan buah di ladang tetapi juga sesuai digunakan untuk menilai kualiti buah yang sampai di kilang pemprosesan minyak. Seterusnya, satu ujian keatas sampel adalah mencukupi untuk meramal masa optimum pemetikan buah dengan menggunakan profil kematangan buah.

CHAPTER 1
INTRODUCTION

The world production of palm oil has been increasing at a rapid pace from about 1.1 metric-million tonnes (MMT) in 1970 to 11.1 MMT in 1990 (FAO, 1990) and is expected to reach 17.4 MMT by the year 2000 (Kaufman, 1993). Currently, Malaysia is the world's leading producer of palm oil where it accounted for about 55 per cent of total global palm oil production as in 1990.

Palm oil is obtained from the mesocarp of the oil palm fruits. Normally a palm tree takes about three years to produce its first fruit bunch. The oil accumulation in the mesocarp starts approximately 14-15 weeks after anthesis and increases rapidly about 20 weeks after anthesis (Thomas *et al.*, 1971; Ng and Southworth, 1973; Ariffin, 1984; Ariffin *et al.*, 1990). After 20 weeks, only a small increase is observed and at the same time the percentage of free fatty acid (FFA) in oil increases as the bunch ages, thus reducing the quality and quantity of the oil (Siregar, 1976; Southworth, 1976). Therefore there will be a time in the life span of each bunch when oil yield and quality are in optimal balance. This optimum time is the time to harvest the bunch. Inefficient harvesting due to insufficient attention to ripeness standards can therefore result in very substantial oil losses since the oil content of the fruit bunch is a function of its degree of ripeness.

An Overview of the Oil Palm Fruit and Bunch

The oil palm fruit is a drupe, 2 to 5 cm long. It consists of a kernel which is encapsulated by the pericarp, made up of exocarp (or skin), mesocarp (or pulp) and endocarp (or shell). The mesocarp contains fibres which run longitudinally through the oil bearing tissue from the base towards the fruit tip. This fibrous material constitutes almost 16% of the mesocarp [Hartley, 1977]. Based on the shell thickness, a fruit or palm may be described as being either *dura*, *tenera* or *pisifera* variety. The *pisifera* is shell-less; many *pisifera* palms fail to set fruit, so the *pisifera* is not commercially important. The other variety *dura* has a thick shell, while *tenera* has a thin shell and high mesocarp content. The *tenera* variety is the type of fruit preferred for commercial use, because more of the pericarp consists of oil bearing mesocarp than in *dura*.

The fruit bunch is ovoid and may reach 50 cm in length and 35 cm in breadth. The bunch consists of the outer and inner fruit and the spikelets stalks and spines, as illustrated in Figure 1. Ripening is usually from the apical to the basal of the bunch and from the outer spreading gradually towards the inner fruits of the spikelet. As the fruit in the bunch ripens, the colour changes from black to reddish orange and the oil content increases in the process. When the oil content reaches a maximum, the fruit becomes loose and falls to the ground.

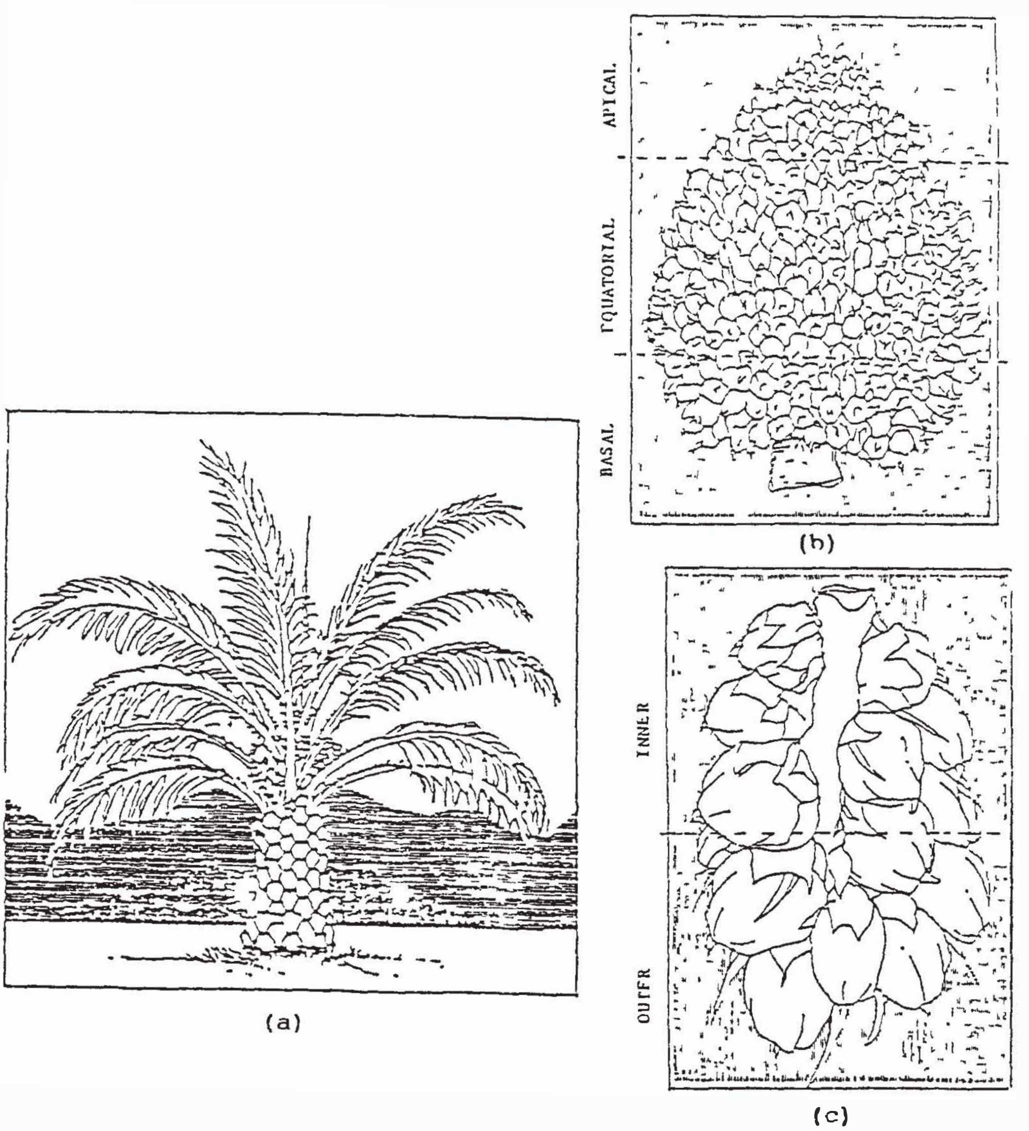


Figure 1. Palm Oil Tree and Bunch (a)Palm Oil Tree (b) Schematic Division of Fruit Bunch (c) The Outer and Inner Halves of a Spikelet

Measure of Ripeness of Oil Palm Fruits

Various techniques to gauge the ripeness of oil palm fruits have been developed based on the visual symptoms such as change of colour in fruits, percentage or number of detached fruits per bunch (Ng and Southworth, 1973) and flotation technique (Ariffin, 1990). The ripeness is normally indicated by the colour changes in the fruit from black to orange or reddish-orange. Unfortunately, the colour change which takes place on ripening is not consistent and varies between individual palms and between geographic areas (Arokiasamy, 1968).

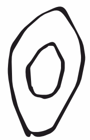
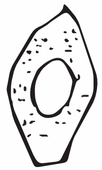
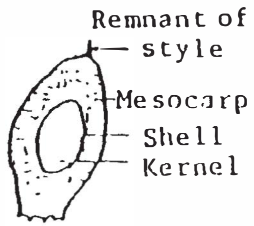
The common practice in the oil palm plantation is using the number or percentage of detached fruits per bunch as a measure of bunch ripeness. The maximum oil yield is found only when the fruit is about to be detached from the bunch (Turner, 1974). However as mentioned earlier, ripening within a fruit bunch is not uniform. In order to solve this problem, various grading schemes of bunch ripeness have been proposed such as 20-25% detached fruits to total fruits (Ng and Southworth, 1973), 2 detached fruits per kilogram of bunch weight (Bevan *et al.*, 1966) or 20 to 40 detached fruits per bunch. These methods however have many drawbacks and objections. Thus the procedure is not accurate as it does not relates to oil quality and quantity. Also it fails to make a distinction between detached fruit on ground and easily detached by hand. In addition due to wide range of bunch size within a population of oil palms, it will result in quite large variations in percent detached fruits/bunch. The principle behind the flotation technique is the fact that the specific gravity of the mesocarp of the ripe fruit is much lower than water. Normally the section of mesocarp at around the tip of the fruit will attain a specific gravity of 0.89. Although this technique is easy to use and quick, it does not determine the absolute oil content in the fruit. A summary of the changes of various parameters: the cross-section of fruits, colour, number of detached fruits, percentage of oil/fresh mesocarp and percentage of FFA in the developing fruit is shown in Table 1.

Another possible parameter that is useful in determining the degree of ripeness is the moisture content of mesocarp. It was found (Ariffin, 1984) that the amount of moisture content is higher at early stage of fruit development. The need to have excess water is reduced in the ripe fruit as the oil accumulates in the mesocarp. Up to approximately 14-15 weeks after anthesis, the amount of water in fresh mesocarp is about 80% and decreases rapidly to about 30-40% in the ripe fruit at 20-23 weeks after anthesis. The decrease in moisture content from 15 to 20 weeks after anthesis is almost the same rate with the accumulation of oil in the mesocarp. Therefore the close relationship between the moisture and oil contents in mesocarp gives a possibility of using percentage of moisture content/fresh mesocarp as a parameter to gauge ripeness.

Microwave Moisture Measurement

The interaction between biological materials with electromagnetic fields can be described by the use of a complex dielectric permittivity ε^* in which the real part, ε' is related

Table 1
Variation in Size, Colour, % Oil/Fresh Mesocarp and
% Free Fatty Acid at Different Stages of Ripeness

Stage of Ripeness (Weeks After Anthesis)	Cross-Section of Fruit	Colour	% Oil/Fresh Mesocarp	% Free Fatty Acid
Young Fruits (7-11)		Black	–	–
Under Ripe (15-17)		Black + Reddish Black	Less Than 5%	–
Mature Fruit (Not Fully Ripe) (18-19)		Reddish Orange	40-48%	Less Than 0.2%
Ripe (20-22)		Reddish Orange + Orange	48-50%	0.26% to 0.5%
Fully Ripe (21-23)		Mostly Orange	More Than 50%	1.3% to 5.0%
Over Ripe (Above 24)		Mostly Orange	More Than 50%	More Than 5.0%