



**UNIVERSITI PUTRA MALAYSIA**

**DEVELOPMENT OF MICROSTRIP ANTENNA SENSOR FOR CONCRETE**

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**DEVELOPMENT OF MICROSTRIP ANTENNA SENSOR FOR CONCRETE**

**By**

**MOHD RAZALI BIN MAT YASSIN**

**Thesis Submitted in Fulfilment of the Requirement for the  
Degree of Master of Science in the Faculty of  
Science and Environmental Studies  
Universiti Putra Malaysia**

**Jun 2001**



## **DEDICATION**

To my wife, Maznah Seman and my children, Asyraf, Akashah, Nur Irfan Daniel and  
Nur Diena Insyirah and memory of My Mother and Father

AL Fathihah



Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

## **DEVELOPMENT OF MICROSTRIP ANTENNA SENSOR FOR CONCRETE**

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The microwave reflection type sensor using microstrip disk antenna is developed. The purpose of developing the sensor is to monitor the fresh concrete hardening and to determine concrete curing point.

The structure of microstrip disk antenna is divided into three parts i.e. radiation surface, substrate and ground plane. This antenna is developed from polytetra fluoroethylene (PTFE) or random microfibre glass substrate (RTD 5880) with dielectric constant  $\epsilon_r = 2.2$ . The RTD 5880 substrate is selected based on its suitability to operate at the resonant frequency of 10.7 GHz.

In developing the microstrip antenna, parameters such as radius of disk, resonant frequency, resistance at resonance, total quality factor, efficiency and bandwidth has to be taken into consideration. The difference between calculation and experimental results of the resonant frequency and resistance at resonance is about 5%.

The measurements on fresh concrete and concrete curing are done in via two techniques namely contact and non-contact. The samples were prepared based on water



to cement ratio 0.5, 0.55 and 0.6. These samples are left to dry in natural condition and at room temperature for 1, 3, 7, 14 and 28 days.

The results of both techniques showed that reflection from non-contact technique have readings higher than 100 mW and was more stable compared to contact technique. The non-touching technique was also easy to manage when applied to fresh concrete compared to the touching technique.

Studies had shown that the power reflection is inversely proportional with concrete curing time. Significant power reflection reduction had occurred during the first three days of curing process. This phenomena was due to accelerated hydration process that happening inside the concrete during that period. As the curing process resumed, hydration process slowed down then reaching approximately a constant rate. It is during this period that the concrete had hardened and gained its strength.

Realising the relationship between microwave, moisture content inside the concrete and concrete strength, the microwave moisture sensor is developed to measure the water or moisture content. This approach can be utilized as a technique in non-destructive testing for concrete to monitor concrete hardening process and predict the anticipated concrete strength in order to fulfill design requirements.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

## **PEMBINAAN SENSOR MIKROSTRIP ANTENA UNTUK KONKRIT**

Oleh

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Sepasang sensor pemantul gelombang elektromagnetik telah dibina dengan menggunakan mikrostrip antena cakera. Sensor ini dibangunkan bertujuan untuk menyelia pengerasan konkrit basah dan untuk menentukan titik perawatan konkrit.

Struktur mikrostrip antenna cakera dibahagikan kepada tiga iaitu permukaan sinaran, substrat dan satah bumi. Antena diperbuat daripada *polytetra fluoroetlene* (PTFE) atau substrat mikrofiber rawak (RTD 5880) dengan pemalar dielektrik  $\epsilon_r = 2.2$ . Substrat RTD 5880 dipilih kerana kesesuaiannya beroperasi pada frekuensi resonan 10.7 GHz.

Beberapa parameter seperti jejari cakera, frekuensi resonan, rintangan pada resonan, faktor jumlah kualiti, kecekapan dan lebar jalur telah dipertimbangkan. Di dapati hanya 5 % sahaja perbezaan antara pengiraan dan eksperimen bagi frekuensi resonan dan rintangan pada resonan.

Pengukuran pantulan gelombang mikro ke atas konkrit basah dan masa perawatan konkrit telah dilakukan dalam dua kaedah iaitu secara sentuhan dan tanpa sentuhan.

Sampel-sampel telah disediakan berasaskan kepada nisbah air ke atas simen sebanyak 0.5, 0.55 dan 0.6. Sampel-sampel ini kemudiannya dibiarkan mengeras secara semulajadi pada suhu bilik untuk tempoh 1, 3, 7, 14 dan 28 hari.

Hasil yang diperolehi daripada kedua-dua teknik menunjukkan pantulan gelombang mikro daripada teknik tanpa sentuhan lebih tinggi dan stabil berbanding teknik sentuhan iaitu lebih daripada 100 mW. Teknik tanpa sentuhan juga senang dikendalikan dan diaplikasikan ke atas konkrit basah.

Kajian menunjukkan pantulan gelombang mikro berkadar songsang dengan tempoh rawatan konkrit. Untuk tempoh tiga hari pertama perawatan, pantulan gelombang mikro menurun dengan mendadakunya. Ini terjadi kerana pada tempoh ini proses hidrasi begitu aktif. Selepas itu proses hidrasi menjadi semakin perlahan dan kemudiannya malar. Ketika proses ini konkrit mula mengeras dan kekuatannya juga meningkat.

Dengan mengetahui perhubungan antara gelombang mikro, kandungan kelembapan dan kekuatan konkrit maka sensor kelembapan gelombang mikro dibangunkan untuk mengukur kandungan air atau kelembapan di dalam konkrit. Pendekatan ini boleh digunakan sebagai satu teknik dalam ujian tanpa musnah ke atas konkrit dalam mengawal proses pengerasan dan meramal kekuatan konkrit bagi memenuhi spesifikasi yang dikehendaki.

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## TABLE OF CONTENTS

	<b>Page</b>
DEDICATION	ii
ABSTRACT	iii
ABSTRAK	v
ACKNOWLEDGEMENTS	vii
APPROVAL SHEETS	viii
DECLARATION FORM	x
LIST OF TABLES	xiv
LIST OF FIGURES	xvi
LIST OF PLATES	xix
LIST OF ABBREVIATIONS	xx
<b>CHAPTER</b>	
1 INTRODUCTION	1
1.1 History	1
1.2 Microwave Aquametry	2
1.3 Concrete	3
1.4 Advantages of Microstrip Antenna	4
1.5 Applications	5
1.6 Objectives of Thesis	6
1.7 Outline of Thesis	7
2 MICROSTRIP ANTENNA	8
2.1 Antennas	8
2.1.1 Parameter of Antenna	12
2.2 Microstrip Antenna Configuration	17
2.2.1 Microstrip Patch Antennas	18
2.2.2 Microstrip Traveling-Wave Antennas	19
2.2.3 Microstrip Slot Antennas	20
2.3 Excitation Techniques	20
2.3.1 Microstrip Feed	20
2.3.2 Coaxial Feed	21
2.4 Circular Microstrip Antenna	22
2.5 Material and Substrate	23
2.5.1 Criteria for Substrate Selection	24
2.6 Summary	28
3 CONCRETE	29
3.1 Properties of Concrete	29
3.1.1 Cement	30
3.1.2 Water	30
3.1.3 Aggregates	31



3.2	Strength of Concrete	31
3.2.1	Water to Cement Ratio (w/c)	32
3.2.2	Shape of Aggregates	33
3.2.3	Curing	33
3.2.4	Durability and Permeability	34
3.3	Fresh Concrete	35
3.4	Fresh Concrete Monitoring	36
3.5	Summary	37
4	MICROWAVE AQUAMETRY	38
4.1	Microwave	38
4.2	Sensor	39
4.3	Microwave Sensor	41
4.4	How Microwave Sensor Works	44
4.5	Summary	48
5	THEORETICAL ANALYSIS	49
5.1	Method of Analysis	49
5.2	Electric and Magnetic Fields	50
5.3	Radiation Pattern	52
5.4	Frequency Resonant	54
5.5	Radius of Disk	61
5.6	Radiation Resistance	63
5.7	Dielectric Losses	64
5.8	Ohmic Losses	65
5.9	Input Impedance	66
5.10	Quality Factor ( $Q_T$ )	70
5.11	Efficiency	71
5.12	Bandwidth	72
5.13	Directivity and Gain	72
5.14	Summary	73
6	METADODOLOGY	74
6.1	Antenna Design	74
6.1.1	Power Radiation	79
6.1.2	Coupling and Orientation Measurements	79
6.2	Sample Preparation	83
6.2.1	Power Penetration into Concrete	83
6.3	Experimental Set-up	84
6.3.1	Measurements Techniques	84
6.4	Summary	86

7	MEASUREMENT RESULTS	87
7.1	The Performance of Antenna	87
7.1.1	Efficiency, Bandwidth and Total Quality of Antenna	87
7.1.2	Radius of Disk	91
7.1.3	Input Impedance	92
7.1.4	Feed Position	94
7.1.5	Resonant Frequency	96
7.1.6	Radiation Pattern	102
7.1.7	Antenna Coupling	105
7.2	Sample (Concrete) Measurements	106
7.2.1	Hydration Process Measurements	106
7.2.2	Power Penetration into Concrete Measurements	109
7.3	Error Analysis	112
8	CONCLUSION AND SUGGESTIONS	113
8.1	Discussion and Conclusion	113
8.2	Suggestions for Future Works	115
	REFERENCE	117
	APPENDICES	121
A	Computer Programs	121
B	Concrete Mixes	125
C	Concrete Mix Design (British Standard)	126
D	Tables of Results	127
	BIODATA OF AUTHOR	139



## LIST OF TABLES

Table		Page
2.1	Comparison of the various type of printed antennas	22
2.2	Properties of Commonly Used Substrate Materials for Microstrip Antennas	25
2.3	Surface Resistive and Skin Depth	27
3.1	The compound in OPC	31
6.1	Properties of the RTD Duroid substrate at 10.7 GHz	76
6.2	The calculation of efficiency, bandwidth, total quality and gain	80
6.3	Trial mixes of $3.375 \times 10^{-6} \text{ m}^3$ for slump 80 – 100 mm.	84
7.1	Efficiency and Total Quality for three substrates	127
7.2	Bandwidth and directivity at different resonant frequency	128
7.3	Radius of microstrip disk antennas	129
7.4	Feed position /Radius of microstrip disk antennas	130
7.5	Comparison between theory and practical for resonant frequency and resistance at resonant	130
7.6	Resistance at resonance for three type of substrate	131
7.7	Input impedance of microstrip disk antenna for real and imaginary component	132



7.8	Radiation pattern of microstrip disk antenna 'A' and 'B'	133
7.9	Coupling and orientation of microstrip disk antennas	134
7.10	Power reflection from concrete during hydration process (non-touching with concrete surface measurements)	135
7.11	Power reflection from concrete during hydration process (touching with concrete surface measurements)	136
7.12	Power reflection from concrete for curing time (non-touching with concrete surface measurements)	137
7.13	Power reflection from concrete for curing time (touching with concrete surface measurements)	137
7.14	Power reflection from steel bar in concrete (touching with concrete surface measurements)	138
7.15	Absolute error of equipments	138



## LIST OF FIGURES

Figure		Page
2.1	Antennas type	11
2.2	Radiation pattern of antenna	16
2.3	Microstrip antenna configuration	17
2.4	Various shape of microstrip antenna	18
2.5	Microstrip traveling-wave antennas	19
2.6	Microstrip disk antenna (a): plan view and (b) side view	22
3.1	The relationship between compressive strength and w/c ratio	32
3.2	Influence of moist curing on the strength of concrete	35
4.1	Electromagnetic spectrum	40
4.2	Free space permittivity methods	45
4.3	Plane wave incident at the right angle on a semi-infinite dielectric	46
5.1	The cross section of circular waveguide	54
5.2	Geometry configuration of fringing in microstrip antenna	60
5.3	The Circuit of parallel RCL	68

6.1	The configuration of microstrip disk antenna	75
6.2	Block diagram and position measurement for radiation pattern	78
6.3	The Mutual coupling measurements	81
6.4	The position of steel bar in concrete	84
6.5	The experimental set-up	85
7.1	The Efficiency and Total Quality three substrate at various frequencies	88
7.2	Directivity of antenna at certain frequency	89
7.3	The bandwidth at certain frequencies for three type of substrate	90
7.4 (a)	Radius of disk at different frequency (Normal graph)	91
7.4 (b)	Radius of disk at different frequency (log graph)	92
7.5	Input Impedance of three-type substrate at different frequencies	93
7.5(a)	Input impedance with frequencies for real component	93
7.5(b)	Input impedance with frequencies for imaginary component	94
7.6(a)	Feed position / radius	95
7.6(b)	Feed position / radius at 50 ohms resistance	95
7.7	Smith Chart for MDA "A"	97





7.8	Measurements of reflected power for MDA “A”	98
7.9	Smith Chart for MDA “B”	99
7.10	Measurements of reflected power for MDA “B”	100
7.11	Resistance at resonance at various frequencies	101
7.12	Radiation pattern for microstrip disk antenna at E-plane	103
7.13	Radiation pattern for microstrip disk antenna at H-plane	104
7.14	Orientation and mutual coupling for microstrip disk antenna	105
7.15	Power reflection by fresh concrete during hydration process (non-contact method)	107
7.16	Power reflection by fresh concrete during hydration process (contact method)	108
7.17	Power reflected by concrete at age of curing day (non-contact method)	108
7.18	Power reflected by concrete at age of curing day (contact method)	109
7.19	Power reflection by steel bar at different depth	110



## LIST OF PLATES

Plate		Page
6.1	Microstrip disk antenna	77
6.2	Microstrip disk antenna analysed by Network Analyzer	77
6.3	The measurements of radiation pattern using microstrip antenna array	80
6.4	Coupling measurements	82
6.5	Equipments for concrete measurements	85
6.6	Measurements of concrete for hydration process	86
7.1	Concrete with good compaction	111
7.2	Concrete with poor compaction	111



## LIST OF ABBREVIATIONS

$\epsilon_r$	relative dielectric constant of material
$\epsilon_0$	dielectric constant of material at free space
$\epsilon$	dielectric constant of material
$\mu_0$	permeability in vacuum
$\mu_r$	relative permeability
$\mu$	permeability of the dielectric
$\lambda$	wavelength
$v_0$	velocity of light in free space
$\eta$	efficiency
$\gamma$	intrinsic propagation constant medium
$\rho$	feed distance from center of disk
$\sigma$	conductivity of conductor
$a$	radius of disk
$a_e$	effective radius
$h$	substrate height
$d\Omega$	element in solid angle
$f_r$	frequency resonant
$k$	wave number of dielectric
$k_0$	wave number of free space
$\Gamma$	reflection coefficient
$\omega$	angular frequency
$w/c$	water to cement ratio
pcf	per cubic feet
R	surface resistivity
T	transmission coefficient
$P_t$	transmitter power
$P_0$	incident power
n	number mode
$\hat{n}$	unit vector normal to the aperture
$\epsilon_r'$	real part of dielectric permittivity
$\epsilon_r''$	imaginary part of dielectric permittivity
I	numerically calculated integral
$E_r$	reflect dielectric field vector
$E_0$	incident dielectric field vector
$f_c$	concrete strength
$f_u$	maximum frequency
$\alpha$	attenuation constant
$\alpha_d$	dielectric loss
$\alpha_c$	conductor loss
$\delta$	loss tangent ( $\tan \delta$ )
D	directivity
$G_e$	effective gain
C	capacitance



L	inductance
$\phi$	cylindrical and spherical azimuth angle co-ordinate
$\theta$	spherical polar angle co-ordinate
$P_r$	total radiated power
Q	total quality factor
R	resonant input resistance
$R_o$	resistance at resonant
$R_{in}$	input resistance
$G_T$	total conductance
$Z_{in}$	input impedance
$W_T$	total stored energy
V	edge of voltage
$\beta$	phase constant
$R_r$	radiation resistance
BW	bandwidth
$E_o$	magnitude of electric field inside the cavity
G	gain
$J_n$	Bessel function of order n
$J'_n$	derivative of Bessel function of order n
NDT	non-destructive testing
MPA	microstrip patch antenna
MTA	microstrip traveling-wave antenna
TEM	transverse electric and magnetic
ISM&D	Industrial, scientific, medical and domestic
$\vec{W}$	instantaneous poynting vector
$\vec{E}$	instantaneous electric field intensity
$\vec{H}$	instantaneous magnetic field intensity
$W_{rad}$	radiation intensity
MMIC	Millimeter wave integrated circuit
IEEE	Institute of Electrical and Electronic Engineering
$U_o$	Radiation intensity of isotropic source
U	radiation intensity
$P_{in}$	total input power
TEM	transverse electric and magnetic
TE	transverse electric
TM	transverse magnetic
RTD	RT Duroid
PTFE	polytetra fluoroethylene
DT	destructive technique
ASTM	American Society for Testing and Materials
TLM	transmission line model
$P_T$	total power loss
VSWR	voltage standing wave ratio
EAM	electromagnetic absorbing material



# CHAPTER 1

## INTRODUCTION

Microstrip antenna has played an important role in history since the 1970's and its development gains rapidly year by year. It has gained lots of attentions to researchers in both military and civilian. In high performance applications such as in aircraft, spacecraft, satellite and missile, where size, weight, performance and aerodynamic profile are the constraints, low profile antenna may be required. There are extensive research and development of microstrip antenna because of numerous advantages such as lightweight, low volume, low cost, planar configuration, compatibility with integrated circuits, etc. Presently there are commercial applications in industries, agriculture and communication that used microstrip antenna.

This chapter reviews the short history of microstrip antenna and current applications in microwave aquametry were also discussed. This is followed by the advantages and applications of microstrip antenna. A brief discussion on concrete and its problems in measurement technique were also included. At the end of this chapter, objectives of this project will be highlighted.

### 1.1 History

Microstrip antennas were widely used as a radiating element. Deschamps in early 1953 was the first person that proposed the concept of microstrip radiator and Munson developed practical antennas in early 1970's (Bahl and Bhartia, 1980). Howell (1975) published and patented the data on rectangular and circular microstrip patches.



The new antenna industry was born after the development of microstrip antenna for rockets by Munson.

The first mathematical analysis of microstrip antenna was published in 1977 by Lo et. al. (1977) who used the model-expansion technique to analyse rectangular, circular, semicircular and triangular patch shapes. This was followed by the increase in the usage of mathematical model which could be used for antenna design (Carver, 1981).

The microwave were introduced in aquametry in the 50s by Freymenn, Walker, Nedzveckki and Watson to determine the relationship between propagation constant and the quantity of water of wet material. The growth of microwave aquametry started since the 1970's. A few reasons for the increase include low cost of installation compared to solid state devices and well established measuring method plus this method is efficient in laboratory or industry (Kraszewski, 1980).

The used of microwave aquametry onto concrete was applied by Reza Zoughi et al. (1991) to estimate the cement paste compressive strength. Reza Zoughi et al. (1991) also used microwave to detect the rebars in concrete and followed by K. J. Bois et al. (1995) to determine the water to cement ratio in fresh Portland Cement.

## **1.2 Microwave Aquametry**

As discussed previously, the application of microwave power in industrial, scientific, medical and domestic (ISM&D) has been developing at a slower space. The total number of professionals, funds and the overall effort involved in the development

of the ISM&D is only at one percent compared to the field of communications and radar.

Microwave energy was used in two main areas: material processing and monitoring electrical and non-electrical quantities. The majority of installations of microwave power were at 2.45 GHz with some at 915 MHz and a few at 433 MHz. Microwave monitoring instrumentation normally used low-power sources to avoid any interference problems.

There were a great variety of applications of microwave power in industries such as chemical, food, rubber, oil, leather, building materials etc. The main advantages of microwave aquametry in processing of materials are increased rate of production, improved product characteristic, uniform processing, low area of space, convenience and controllability of process.

### **1.3 Concrete**

There are hundreds of systems of concrete mix design. The design concrete is mixed based on the desired strength. The design of a structure is based on the assumption of certain properties of the materials to be used and their proportion. The main property in concrete is strength, which should be able to carry dead, imposed and winds load. The actual strength of a material is a variable quantity, which depends on testing procedure, mixes constituents, placing, compaction, hardening temperature and curing.

The common testing process on concrete was through measurement of compressive strength on concrete tubes that were produced during construction process