UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT OF MICROSTRIP ANTENNA SENSOR FOR CONCRETE

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By

MOHD RAZALI BIN MAT YASSIN

Thesis Submitted in Fulfilment of the Requirement for the
Degree of Master of Science in the Faculty of
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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

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Chairman: Professor Kaida b. Khalid, Ph.D.

Faculty: Science and Environmental Studies

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 fluoroethlene (PTFE) or random microfibre glass substrate (RTD 5880) with dielectric constant ε_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

MOHD RAZALI BIN MAT YASSIN

Jun 2001

Pengerusi: **Profesor Kaida b. Khalid, Ph.D.**

Fakulti: **Sains dan Pengajian Alam Sekitar**

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 ε_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 dikendali 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 mendadaknya. 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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This thesis submitted to the Senate Universiti Putra Malaysia has been accepted as fulfilment of the requirement for the degree of Master of Science.

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ε_r	relative dielectric constant of material
ε_o	dielectric constant of material at free space
ε	dielectric constant of material
μ_o	permeability in vacuum
μ_r	relative permeability
μ	permeability of the dielectric
λ	wavelength
v_o	velocity of light in free space
η	efficiency
γ	intrinsic propagation constant medium
ρ	feed distance from center of disk
σ	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_o	wave number of free space
Γ	reflection coefficient
ω	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
ε_r'	real part of dielectric permittivity
ε_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
α	attenuation constant
α_d	dielectric loss
α_c	conductor loss
δ	loss tangent (tan δ)
D	directivity
G_e	effective gain
C	capacitance

L	inductance
ϕ	cylindrical and spherical azimuth angle co-ordinate
θ	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
β	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 fluoroethlene
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, Nedzvecki 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 deed, 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