



UNIVERSITI PUTRA MALAYSIA

**DEVELOPMENT OF A DUAL FREQUENCY MICROWAVE MOISTURE
SENSOR SYSTEM BASED CIRCULAR MICROSTRIP ANTENNA**

MOHAMED MUSTAFA GHRETLI.

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By

MOHAMED MUSTAFA GHRETLI

**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia,
in Fulfilment of the Requirement for the Degree of Doctor of Philosophy**

October 2005



*In
memory of my Mother,
the bright candle in my life.*



Abstract of thesis presented to the Senate of Universiti Putra Malaysia in
fulfilment of the requirement for the degree of Doctor of Philosophy

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October 2005

Chairman: Professor Kaida Khalid, PhD

Faculty: Science

A dual frequency microwave moisture sensor based on far field reflection technique using two circular microstrip antenna pairs was developed and used to measure moisture content of various lossy liquid solutions. The sensor used two dielectric resonator oscillators as microwave sources in the X-band with oscillating frequencies of 8.48 and 10.69 GHz. Two wideband coaxial detectors were used to measure the amplitude of the reflected signals.

Theoretical calculation based on quasi-static cavity model with infinite ground plane approximation for circular microstrip antenna was carried out to evaluate design parameters such as antenna radius at resonance, efficiency, gain, bandwidth, feed point location ...etc. To this end a Visual Basic program was written and documented to evaluate all the design parameters needed



Antennas edge separation distances and E-plane configurations were considered carefully to reduce mutual coupling between elements. The final layout was printed on a single dielectric substrate. Radiation characteristics of the antennas, S-parameters and input impedances at resonance were measured using vector network analyzer and they compared satisfactory to theoretical simulations.

The optimum thickness of the sample holder and the air gap between the antennas and the sample holder were evaluated experimentally to ensure maximum signals at the detectors. Good agreements to theoretical expected values were found. The analysis of the complex electromagnetic waves in this reflected-type system is presented using signal flow graphs and solved by Mason's non-touching loops rules. The whole sensor system was interfaced to a personal computer through data acquisition card. This automated the calibration procedures and facilitated the switching time between the sources. Graphical user interface panel was written in LabView language to guide the user through calibration measurements and.

As an application example, the whole system was tested using diluted rubber latex with moisture content ranging from 39.8 to 95.2% wet basis. The sensor has predicted moisture contents with standard error of performance of $\pm 0.49\%$ moisture content using weighted average calibration method. Moisture contents of latex samples in temperature range of 25 to 63°C were measured successfully with an accuracy of $\pm 1.3\%$ MC wet basis compared to standard oven drying method.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai
memenuhi keperluan untuk ijazah Doktor Falsafah

**PEMBINAAN FREKUENSI DUAL PENDERIA MIKROGELOMBANG
KELEGASAN BERGANTUNG KEPADA ANTENA BULAT MIKROJALUR**

Oleh

MOHAMED MUSTAFA GHRETLI

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Fakulti: Sains

Penderia kelegasan frekuensi dual mikrogelombang dibina berasaskan teknik pantulan medan dekat dengan menggunakan dua pasang antena bulat mikrojalur dan digunakan untuk mengukur kandungan kelegasan pelbagai campuran cecair ketidakhilangan. Penderia itu menggunakan dua pengayun resonan dielektik, DROs sebagai punca pengayun gelombang pada frekuensi jalur-X dengan menjanakan frekuensi antara 8.48 dan 10.69 GHz. Dua jalur lebar pengesan sepaksi digunakan untuk mengukur amplitud isyarat pantulan.

Kiraan teori yang berasaskan model rongga kuasi-statik dengan satah substat tak terhingga penghampiran antena bulat mikrojalur telah digunakan untuk menilai parameter rekabentuk seperti jejari antena pada frekuensi resonan, kebekesanan

gandaan, lebar jalur, kedudukan titik sua dan lain-lain lagi. Dengan itu, satu program Visual Basic telah ditulis dan didokumenkan untuk mengira parameter rekabentuk yang diperlukan dan juga untuk menjangka keterusan antenna dan E&H satah bentuk radiasi. Unsur impedan masukan radiasi telah dikira berasaskan pertengahan kedudukan titik suap dan juga paduan kepada komponen sistem yang lain untuk hataran kuasa maximum. Bentangan unsur berasaskan sudut pamecahan dan satah E&H konfigurasi adalah ditimbang dengan teliti untuk pengurangan saling ganbungan unsur antenna itu. Bentangan terakhir yang dicetak pada substrat dielektik dan setiap unsure disambung kepada punca atau pengesan yang berkaitan melalui sambungan SMA sepaksi. Cirri-ciri radiasi unsur antenna, parameter S dan impedan masukan pada resonan diukur menggunakan VNA sempurna dibanding dengan teori simulasi.

Pengoptimuman ketebalan pemegang sample dan pemisahan jarak antara antenna dan pemegang sample telah diadakan secara eksperimen untuk memastikan pengesan isyarat masimum pada pengesan bergantung kepada posisi masimum pertama dengan baik berbanding jangkaan teori. Analisa elektromagnetik gelombang kompleks pada sistem jenis pantulan adalah disebarkan dengan menggunakan graf gerakan isyarat. Nisbah gelombang kompleks pada titik mana-mana dalam sistem kepada isyarat masuk pada punca rujukan diperolehi dengan menggunakan peraturan Manson's perantaraan ulangan tak-sentuk untuk memudahkan analisis dan menghasilkan sistem pelbagai lapis, satu perisian, Tran&REF telah ditulis untuk mengira pantulan setiap lapisan perantaraan dalam sistem sehingga 6 lapisan. Perisian juga menyertakan telitian analisa setiap perantaraan dan pantulan kiraaan dan juga kulit dalaman pada kedua-dua media pada pinggir antaraan.

Keseluruhan sistem penderia adalah diantaramukakan kepada satu komputer persendirian melalui kad pengantaraan muka National Instrument DAQ. Ia mempunyai kaedah automatik pententu-ukuran dan kedudukan pelaras masa antara punca. Akhir sekali, perisian ditulis dengan labView untuk sistem penderia dengan gambaran pengguna antaraan-muka mudah . Ia mengarah pengguna dalam beberapa langka bagaimana untuk jalankan pengukuran, simpan dan cetak file. Tanda amaran jelas ditayang jika tentu-ukur baru diperlukan. Dua papan elektronik berdedikasi telah dihasilkan dengan perisian Ultiboard. Tujuan pertama papan ialah untuk membekal voltan kepada pengayun dan lindungan daripada voltan berlebihan dan gandakan isyarat keluaran. Papan kedua menempatkan masukan analog dan sambungan pin antena digit kepada papan pengantaraan muka data dan kawal penentu punca melalui geganti keadaan pepejal.

Sebagai contoh aplikasi, keseluruhan sistem telah dicuba dengan menggunakan getah pada kandungan kelegasan daripada 39.8% sehingga 95.2% asas basah dan telah dijangkakan kandungan kelegasan dengan ketidakpastian piawai 0.49% kandungan kelegasan menggunakan kaedah penentuukuran timbang purata. Kandungan kelegasan sampel getah dalam julat suhu 25°C hingga 63°C telah berjaya diukur pada suhu berasingan. Kaedah penentu-ukur guna nisbah kuasa pantulan 2 jenis frekuensi dan teknik telah mengangkakan kandungan kelegasan asing pada suhu dengan ketidakpastian purata piawai 1.3% kandungan kelegasan asas basah.

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TABLE OF CONTENTS

	Page
DEDICATION	ii
ABSTRACT	iii
ABSTRAK	vi
ACKNOWLEDGEMENTS	vii
APPROVAL	ix
DECLARATION	x
LIST OF TABLES	xvi
LIST OF FIGURES	xviii
LIST OF ABBREVIATIONS	xxiii
LIST OF SYMBOLS	xxiv
CHAPTER	
1 GENERAL INTRODUCTION	
1.1 Microwave Non-Destructive Testing	1
1.2 Measurement of Moisture Content	2
1.3 Advantages of Microwave Sensors	4
1.4 Physical Properties Affecting Moisture Determination	5
1.5 Drawbacks of Current Moisture Sensors	6
1.6 Objectives	7
1.7 Thesis Outline	8
2 LITERATURE REVIEW	
2.1 Microstrip Antenna Technology	10
2.2 Microstrip Transmission Lines	12
2.3 Physical Properties Affecting Moisture Determination	14
2.4 Properties of Materials	16
2.4.1 Frequency Dependence	18
2.4.2 Complex Dielectric Spectrum of Water	19
2.4.3 Complex Dielectric Spectrum of Rubber Latex	21
2.4.4 Moisture Content Dependence	24
2.4.5 Temperature Dependence	25
2.5 Summary	27
3 MICROWAVE ANTENNAS AND TECHNIQUES	
3.1 The Microwave Domain	30
3.2 Antennas	31
3.3 Properties of Antenna	33
3.3.1 Far-Field Region and Radiation Pattern	33
3.3.2 Power Density	35
3.3.3 Radiation Intensity and Directivity	36
3.3.4 Efficiency and Gain	37
3.3.5 Half-power Beam Width and Bandwidth	39



3.3.6	Polarization and Polarization Loss Factor	39
3.3.7	Effective Aperture and Antenna Equation	40
3.3.8	Input Impedance	43
3.4	Types of Microwave Antennas	44
3.4.1	Horn Antenna	44
3.4.2	Slot Antenna	45
3.4.3	Array Antenna	46
3.5	Microstrip Antenna	47
3.5.1	Advantages of Microstrip Antennas	47
3.5.2	Excitation Techniques	49
3.5.3	Types of Flat Profile Printed Antennas	51
3.5.4	Circular Microstrip Antennas	52
3.5.5	Circular versus Rectangular Patch Antenna	53
3.5.6	Substrate Materials	54
3.6	Limits of Microwave Testing	58
3.7	Techniques for Characterization	59
3.8	Reflection Methods	60
3.8.1	Open-Circuit Reflection	60
3.8.2	Short-Circuit Reflection	62
3.8.3	Free-Space Reflection Method	64
3.9	Transmission/Reflection Methods	67
3.10	Resonators Method	69
3.11	Microwave Energy and Safety	71
3.12	Summary	73
4	THEORETICAL ANALYSIS	
4.1	Methods of Analysis	76
4.2	The Cavity Model	76
4.2.1	Electric and Magnetic Fields TM_{nm0}^z	78
4.2.2	The Radiated Far-Fields	81
4.2.3	Resonant Frequency	82
4.2.4	Radiated Power	84
4.2.5	Resonant Input Resistance	86
4.2.6	Directivity	88
4.2.7	Quality Factor	88
4.2.8	Efficiency, Gain and Bandwidth	90
4.2.9	Input Impedance	91
4.3	Plane Wave Reflection	92
4.4	Reflection and Transmission at Multiple Interfaces	94
4.5	System Signal Flow Graph	95
4.6	Summary	99
5	METHODOLOGY	
5.1	General Description of the System	100
5.2	The Single Element Antenna design	101
5.3	Performance Tests	104
5.3.1	Resonance Frequency and Input Impedance	105
5.3.2	E&H-Plane Radiation Patterns	105
5.4	Mutual Coupling and Orientation Measurements	107



5.5	Antennas Configuration	109
5.6	Dielectric Resonant Oscillators, DRO's	111
5.7	Schottky Wide band Detectors	112
5.8	Main Control Board	113
5.9	Interfacing and Graphical User Interface Program	114
5.10	Samples Preparations	115
5.11	Summary	117
6	RESULTS AND DISCUSSION	
6.1	The Performance of Antenna	118
6.1.1	Efficiency and Total Quality Factor	119
6.1.2	Gain and Bandwidth	121
6.1.3	Radius of Disk	123
6.1.4	Resonant Input Resistance	125
4.1.5	Feed Location distance	127
6.1.6	Radiation Patterns	129
6.1.7	Antennas Mutual Coupling	131
6.2	S-Parameters Measurements Using Network Analyzer	133
6.2.1	Antennas pair for f_1	134
6.2.2	Antennas pair for f_2	137
6.3	The Sensor System Configuration Geometry	140
6.3.1	Sample level Consideration	141
6.3.2	Holder Plate Thickness Consideration	145
6.3.3	Air Distance Separation Consideration	147
6.3.4	Warm-Up Time Consideration	149
6.4	Moisture Content Determination Results	150
6.4.1	Single Variable Calibration for f_1	150
6.4.2	Single Variable Calibration for f_2	153
6.4.3	The Average Method of Prediction	154
6.4.4	Weighted Average Method of Prediction	155
6.4.5	Multivariate Regression Calibration Method	157
6.5	Temperature-Independent Calibration Method	162
6.6	Development of prototype Liquid Moisture Meter	172
6.7	Summary	175
7	CONCLUSION AND FUTURE DIRECTIONS	
7.1	Conclusion	177
7.2	Future Directions	180
	REFERENCES	184
	APPENDICES	188
	BIODATA OF THE AUTHOR	220



LIST OF TABLES

Table	Page
3.1 IEEE microwave band Designation.	31
3.2 Comparison of Various Flat Profile Printed Antennas	52
3.3 Comparison of Characteristics of Rectangular and Circular Microstrip Antennas	53
3.4 Characteristics of Commonly Used Microstrip Laminates	55
4.1 Roots of the Derivative of the Bessel Function $J'_n(ka)=0$	81
5.1a Design parameters for RT Duroid substrates at $f = 8.48$ GHz	102
5.1b Design parameters for RT Duroid substrates at $f = 10.69$ GHz	103
5.2 Dielectric Resonator Oscillators' Specifications	112
5.3 Zero Bias Schottky Coaxial Detector's Specifications	112
6.1 Measured Mutual Coupling between Two Coax-Fed Circular Microstrip Antennas, for both E-plane and H-Plane Coupling	132
6.2 Vector Network Analyzer Measurements for A1, A2, B1 and B2 Antennas	138
6.3 Standard Moisture Content and Calibration Data with Residuals at Operating Frequency 8.48 GHz	152
6.4 Standard Moisture Content and Calibration Data with Residuals at Operating Frequency 10.69 GHz	153
6.5 Standard and Predicted Moisture Content for Rubber Latex Samples Using the Average Method	155
6.6 Standard and Predicted Moisture Content for Rubber Latex Samples Using the Weighted Average Calibration Method	156
6.7 Multivariate Calibration Method Results with Residuals	



	for Hevea Latex Calibration Group	159
6.8	Predicted Moisture Content for Validation Group Using Multivariate Calibration Technique	161
6.9	Slopes of Γ_1 versus Γ_2 lines with equivalent radial angle	169
6.10	Measurements Values for Temperature-Independent Calibration	170



LIST OF FIGURES

Figure		Page
2.1	Mechanisms Contributing to the Value of the Effective Loss Factor as a Function of Frequency	18
2.2	Real and Imaginary Part of the Complex Permittivity, ϵ of Water Plotted <i>versus</i> Frequency	20
2.3	Complex Dielectric Properties of Hevea Latex as a Function of Frequency, (a) Dielectric Constant, (b) Dielectric Loss Factor	23
2.4	Complex Dielectric Properties of Hevea Rubber Latex versus MC%, at 0.3 GHz.	24
2.5	Complex Dielectric Properties of Hevea Rubber Latex versus MC%, at 9.3 GHz	25
2.6	Complex Dielectric Properties of Hevea Rubber Latex versus Temperature (a) Dielectric Constant, (b) Dielectric Loss Factor	26
3.1	The Electromagnetic Spectrum	30
3.2	Antenna as a Transition Device	32
3.3	Typical Power Pattern Presentation for an Antenna	34
3.4	Principal E-and H-plane Patterns for a Pyramidal Horn Antenna	35
3.5	PLF for Transmitting and Receiving Aperture Antennas	40
3.6	Geometrical Orientations of Transmitting and Receiving Antennas	41
3.7	Waveguide Antennas (a) E-field Flared Horn and (b) H-field Flared Horn	45
3.8	Slots in a Waveguide Used as Radiating Antennas	46
3.9	Coaxial Feed of a Patch Antenna	49
3.10	Microstrip Line Feed Rectangular Patch Antenna	50
3.11	Aperture-Coupling Feed Patch Antenna	51



3.12	Open-Circuit Reflection Terminated by a Semi-Infinite Sample	61
3.13	Various Measurement Arrangements for Open-Circuit Reflection	62
3.14	A sample Inserted in a Short-circuited Transmission Line	62
3.15	Free-Space Reflection Method	65
3.16	The Setup of Free-space Bi-static Reflection Measurement	67
3.17	Typical Resonators with Different Coupling Schemes	70
4.1	Geometry of Circular Microstrip Patch Antenna	77
4.2	Field Patterns for Circular Microstrip at Resonance Condition	80
4.3	Fringing Geometry of the Field in Microstrip Antenna	83
4.4	The Equivalent Parallel RLC Circuit for Microstrip Antenna	91
4.5	The Geometry of a Propagating Plane Wave in the Positive z Direction Incident on a Plane Interface between Two Regions	92
4.6	Multiple Reflection and Transmission Propagation Paths for Plane Wave through Different Media	94
4.7	Free-Space Reflection System Setup	95
4.8	Signal Flow Graph Representation of the Sensor System as a Cascaded Two-Port Network	96
5.1	Schematic General Layout of the Sensor System	101
5.2	Front panel for the Circular Microstrip Antenna Design, proANT	102
5.3	Schematic Design Proposed for a Single Microstrip Antenna	104
5.4	Schematic Experimental Setup for Radiation Pattern Measurements	106
5.5	Experimental Setup for Radiation Pattern Measurements in the E-plane and H-plane	107
5.6	Configuration for Two Circular microstrip antennas, (a) E-plane Coupling and (b) H-plane coupling	108
5.7	Experimental Setup Diagram for Mutual Coupling Measurements	109



5.8	Top and Bottom View of the Sensor Patch.	110
5.9	Testing Sensor Patch Using HP 8720B Vector Network Analyzer	110
5.10	Schematic Diagram for the Sensor Patch with Connectors	111
5.11	Various Components Used in the Moisture Meter System	113
5.12	Schematic Diagram for Electronic Switching Board	114
6.1	Efficiency vs. Frequency for Different Dielectric substrate Antennas	119
6.2	The Total Quality Factor, Q_T for Three Different Dielectric Substrates	120
6.3	The Gain, G_e for the Dielectric Substrates	121
6.4	The Bandwidth, BW for the Different Dielectric Substrates	123
6.5a	Variation of Radius with Resonant Frequency for Different Dielectric Substrate Antennas (Linear Scale)	124
6.5b	Variation of Radius with Resonant Frequency for Different Dielectric Substrate Antennas (Log Scale)	125
6.6	The Variation of Resistance of Circular Microstrip Antenna versus Frequency for the Three Different Substrates at $f_r = 8.48$ GHz	126
6.7	Reactive Component of the Input Impedance for Circular Microstrip Antenna versus Frequency for Three Different Substrates at $f_r = 8.48$ GHz	126
6.8	Variation of Resonance Resistance as a Function of Feed Point Location for the substrates at 8.48 GHz	128
6.9	The Theoretical E&H-Plane Patterns for Circular Microstrip Antenna as Simulated by proANT.	129
6.10	Experimental E&H-Plane Radiation Power Patterns for Circular Microstrip Antenna with Central Frequency 8.48 GHz	130
6.11	Measured and calculated mutual coupling between the two coax-fed Microstrip antennas, for both E-plane and H-plane coupling	132
6.12	S_{11} Parameter (Return Loss) and Smith Chart; for Circular Microstrip Antenna A1 Fabricated on RTD 5880 Laminate with Resonant Frequency of 8.388 GHz.	134



6.13	S_{22} Parameter (Return Loss) and Smith Chart; for Circular Microstrip Antenna A2 Fabricated on RTD 5880 Laminate with Resonant Frequency of 8.510 GHz.	136
6.14	(a) S_{11} for Antenna B1, (b) Smith Chart for Antenna B1, (c) S_{22} for Antenna B2 and (d) Smith Chart for Antenna B2 all on RTD 5880.	138
6.15	S_{12} Spectrum for (a) Antennas A1 and A2 and (b) Antennas B1 and B2, (reflection from semi-Infinite water medium placed 16.5mm).	139
6.16	Theoretical Normalized Reflected Power <i>versus</i> Water Column Height for Various Perspex Thicknesses	141
6.17	Theoretical and Experimental Reflected Power <i>versus</i> Latex and Water Column Heights.	143
6.18	Normalized reflected power versus the thickness of the Perspex plate	145
6.19	The reflection coefficient Phase versus Perspex Plate thicknesses with Water Column Height of 50 mm at 10.0 GHz	146
6.20	Theoretical Simulation of the Reflected Coefficient Magnitude <i>versus</i> Air layer distances.	147
6.21	Experimental Optimization of Air Distance between Perspex Holder Interface and Transmitting and Receiving Antennas Plane	148
6.22	Detected Voltages at Receiving Antennas Outputs <i>versus</i> Time	149
6.23	The Calibration Curve for Moisture Content Measurements of Hevea Latex at Operating Frequency of 8.48 GHz	152
6.24	The Calibration Curve for Moisture Content Measurements of Hevea Latex at Operating Frequency of 10.69GHz	154
6.25	Standard versus Predicted Moisture Content for Rubber Latex Samples Using the Weighted Average Calibration Method	157
6.26	Predicted and Standard Moisture Contents for Rubber Latex Solutions Using Multivariate Regression Calibration Method	160
6.27	Reflected Signal Voltages, Γ_1 <i>versus</i> Temperature at $f_1 = 8.48$ GHz for Different Moisture Content Values of Rubber Latex Samples	164
6.28	Reflected Signal Voltages Γ_2 <i>versus</i> Temperature at $f_1 = 10.69$ GHz for Different Moisture Content Values of Rubber Latex Samples	165

6.29	Normalized Reflection Ratios <i>versus</i> Temperature for Different Moisture Contents Solutions	167
6.30	Reflected Signal at 10.69 GHz, Γ_2 <i>versus</i> Reflected Signal at 8.48 GHz, Γ_1 for Six Different MC Rubber Latex Solutions in Temp. range of 25°C to 63°C.	168
6.31	Standard Moisture Content <i>versus</i> Averaged Reflected Signal Ratio for Diluted Rubber Latex Solutions	170
6.32	Predicted Moisture Content by Temperature-Independent Calibration <i>versus</i> Oven-Dried Standard Moisture Content	171
6.33	Graphical User Interface of LatexoMeter1, (a) Main Control Panel and (b) System Calibration Panel	173
6.34	Application of Meter System for Moisture Measurement of Rubber	174
7.1	Dual Frequency Microstrip Disk Antenna Using Two Planar Strips	181
7.2	Automatic Leveling Circuit Terminated with Transmitting Antenna	182

LIST OF ABBREVIATIONS

DRO	Dielectric Resonant Oscillator
VCO	Voltage Controlled Oscillator
VNA	Vector Network Analyzer
MMIC	Monolithic Microwave Integrated Circuit
DRC	Dry Rubber Content
MUT	Material Under Test
MC	Moisture Content
HPBW	Half-Power Beam Width
BW	Bandwidth
PLF	Polarization Loss Factor
SEC	Standard Error of Calibration
SEP	Standard Error of Performance
NDT	Non Destructive Testing
VSWR	Voltage Standing Wave Ratio
TEM	Transverse Electric Magnetic Fields
RF	Radio Frequency
HF	High Frequency
VHF	Very High Frequency
UHF	Ultra High Frequency
VB	Visual Basic
d.b.	Dry Basis Moisture Content Determination
w.b.	Wet Basis Moisture Content Determination



LIST OF SYMBOLS

E	Electric Field Intensity	(V/m)
H	Magnetic Field Intensity	(A/m)
S	Poynting Vector	(W/m ²)
ϵ_0	Permittivity of Vacuum	(F/m)
μ_0	Permeability of Vacuum	(H/m)
ϵ_r^*	Relative Permittivity (Complex)	(dimensionless)
μ_r^*	Relative Permeability (Complex)	(dimensionless)
η^*	Medium Impedance (Complex)	(Ω)
L	Inductance	(H)
C	Capacitance	(F)
R	Resistance	(Ω)
G	Conductance	(S)
X	Reactance	(Ω)
B	Susceptance	(S)
Z	Impedance	(Ω)
Y	Admittance	(S)
γ^*	Propagation Constant (complex)	(1/m)
α	Attenuation constant	(1/m)
β	Phase Constant	(rad/m)
δ	Skin Depth	(m)
σ	Conductivity	(S/m)
ω	Angular Frequency	(rad.Hz)



ε'	Dielectric Constant	(F/m)
ε''	Loss Factor	(F/m)
$\tan\delta$	Loss Tangent	(dimensionless)
Γ^*	Reflection Coefficient (complex)	(dimensionless)
τ^*	Transmission Coefficient (Complex)	(dimensionless)
D	Directivity	(dimensionless)
G	Gain	(dimensionless)
e	Efficiency	(dimensionless)
Q_T	Quality factor	(dimensionless)
RL	Return Loss	(dB)
M	Mutual Coupling	(dB)
a	Radius of the Disk	(cm)
ρ_0	Feed Radius	(cm)