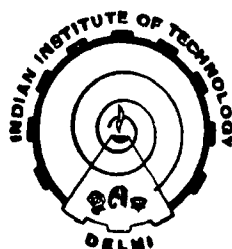


STUDIES ON MICROWAVE INDUCED PLASMAS LOADED WITHIN HELICAL SLOW WAVE STRUCTURES

By
P. APPALA NAIDU

*THESIS SUBMITTED TO THE
INDIAN INSTITUTE OF TECHNOLOGY, DELHI
FOR THE AWARD OF THE DEGREE
OF
DOCTOR OF PHILOSOPHY*



**DEPARTMENT OF PHYSICS
INDIAN INSTITUTE OF TECHNOLOGY, DELHI
INDIA**

March, 1989

A tiny dew dedicated to

AMMA
(mother)

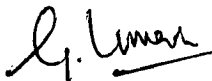
Blessing from the Bliss

CERTIFICATE

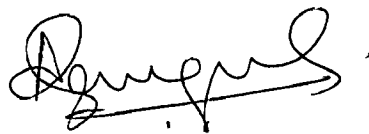
This is to certify that this thesis entitled STUDIES ON MICROWAVE INDUCED PLASMAS LOADED WITHIN HELICAL SLOW WAVE STRUCTURES, being submitted by P. Appala Naidu to the Indian Institute of Technology, Delhi is a record of bonafide research work carried out by him. He has worked under our guidance and supervision and has fulfilled the requirements, which to our knowledge, have reached the requisite standard for the submission of this thesis. The results contained in this thesis have not been submitted in part or full to any other University or Institute for the award of any degree or diploma.



Prof.D.P.Tewari
Physics Department
I.I.T.Delhi
New Delhi-110016
INDIA.



Dr.G.Umesh
Physics Department
I.I.T.Delhi
New Delhi-110016
INDIA.



Dr.A.Ganguli
Centre for Energy Studies
I.I.T.Delhi
New Delhi-110016
INDIA.

ACKNOWLEDGEMENTS

It is my duty to thank Prof.M.S.Sodha and Prof.D.P.Tewari, the Principal Investigators of two successive projects "Wave Propagation in Space Plasmas" (financed by ISRO-India) and "High Power Microwave-Plasma Interaction Studies" (financed by DST-India), for providing me an opportunity to work in the projects and also for their constant encouragement. I once again thank Prof.D.P.Tewari for his valuable guidance throughout the work.

I thank, with a deep sense of gratitude, Dr.A.Ganguli, for suggesting me the problem and guiding the work throughout. It is difficult to find words to express out my heart-felt gratitude. But for his sincere and restless efforts, it would be impossible for me to complete the thesis work, started at the begining of the system development of the projects of this kind, within the time I spent for it. I am equally grateful to Dr.G.Umesh for his guidance; his softness and sincerity are the strength and hope guiding towards the goal.

I thank Prof.V.K.Tripathi, Dr.D.Subba Rao and Dr.G.V.R.Raju for their cooperation and encouragement. I thank Dr.H.D.Pandey who helped me a lot when he was associated with the projects.

It is a pleasure to thank Dr.R.Baskaran, my co-researcher for his cooperation. I am extremely grateful to Mr.V.K.Talwar and Mr.A.J.Josekutty for their skillful technical services and for sharing my anxiety without which it is difficult to complete the work within this time. I thank Miss Indu Dhingra, Mrs.Surabhi Lal and Mr.R.K.Jarwal who, being associated with the projects at some time or other, were very helpful to me.

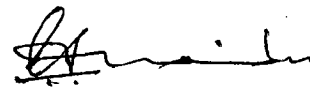
I would like to acknowledge with thanks the services of M/s. Ashok Paul & Co., New Delhi and M/s. Vacuum Equipment Co., New Delhi, who fabricated some of the components of the experimental set-up fulfilling the requirement of fineness as well as urgency. My thanks are also due to the staff of workshops of Dept. of Physics, Centre for Energy Studies and IDDC of IIT, Delhi for readily tendering their technical services.

I am thankful to the Jawaharlal Nehru Technological University, Andhra Pradesh, for deputing me to IIT, Delhi under Quality Improvement Programme sponsored by Govt. of India. I feel indebted to my colleagues who, by virtue of the programme, have shared among themselves my teaching work load and also to the student community who have missed my service for which I have been paid. I am particularly grateful to Prof.P.S.Kesava Rao of JNT University for his constant encouragement. I thank Prof.P.Kameswara Rao of JNT University for his encouragement. I

also thank my colleague Mr.V.Sankar for his constant help and cooperation.

I wish to record the subtle contribution of my wife, Smt.P.Yasoda to the present work; she has been cautiously reminding me of my duty besides taking the whole burden of guiding our young daughters. Her patience and courage, love and fondness to research enabled me to concentrate on the thesis work. I am also grateful to my father, uncles and many other well wishers for their love from which I always derive the spirit for working well throughout my career, the present work being a part of it.

Finally, I thank Mr.R.P.Kapoor for tracing the diagrams neatly and Mr. Samsheer S. Dagar and group of Friends Computer Centre, New Delhi for fast and fine typing of the thesis.



(P.APPALA NAIDU)

CONTENTS

CHAPTER		PAGE
1	INTRODUCTION	1
1.1	SLOW WAVE STRUCTURES IN PLASMAS	5
1.2	HELICAL SLOW WAVE STRUCTURES	9
1.3	OUTLINE OF THE THESIS	15
2	DOMINANT ELECTROMAGNETIC MODES OF A HELIX LOADED WAVEGUIDE	19
2.1	DISPERSION RELATION OF A TAPE HELIX LOADED IN A WAVEGUIDE	21
2.2	THE DOMINANT HARMONIC AND ITS PROPERTIES	30
2.3	ASYMPTOTIC FORMULAE FOR DOMINANT HARMONICS	33
2.3.1	Slow Dominant Wave Mode	33
2.3.2	Fast Dominant Wave Modes	38
2.3.3	Discussion on Asymptotic Formulae	39
2.4	COMPARISON OF THE THEORY WITH EXPERIMENT	44
2.4.1	$k_v r_h < 1$	45
2.4.2	$k_v r_h > 1$	46
2.5	DISPERSION RELATION OF A SLOTTED HELIX LOADED IN A WAVEGUIDE	49
2.6	NUMERICAL RESULTS AND DISCUSSION	53

3	HIGH FREQUENCY MODES OF A PLASMA LOADED HELIX	58
3.1	PLASMA LOADED TAPE HELIX-WAVEGUIDE SYSTEM	58
3.2	PLASMA LOADED SHEATH HELIX	62
3.3	PLASMA LOADED WAVEGUIDE	67
3.4	NUMERICAL RESULTS AND DISCUSSIONS	69
3.4.1	Dispersion Curves	70
3.4.2	Field Amplitudes	76
3.4.3	Polorization	79
4	EXPERIMENTAL SYSTEM AND DIAGNOSTICS	83
4.1	THE EXPERIMENTAL SYSTEM	83
4.1.1	The Plasma Chamber	84
4.1.2	The Vacuum System	84
4.1.3	The Electromagnet Coils and Power Supplies	85
4.1.4	The Water Cooling Systems	88
4.2	HIGH POWER MICROWAVE LINE	88
4.2.1	High Power Attenuator	93
4.2.2	High Power Coaxial Line	94
4.2.3	Vacuum Seal	95
4.2.4	Triple Stub Tuner	96
4.2.5	Operational Difficulties	99
4.3	PLASMA DIAGNOSTICS	102
4.3.1	Langmuir Probe	102
4.3.2	Electron Energy Analyzer	108
4.3.3	Emissive Probe	118
4.3.4	Microwave Probes	120
4.3.5	Signal Observation	121

5	PLASMA PRODUCTION AND CHARACTERIZATION USING HELICAL STRUCTURES	122
5.1	EXPERIMENTAL PROCEDURE	123
5.2	DESIGN AND EXCITATION OF THE HELICAL ANTENNA FOR PLASMA PRODUCTION	125
5.2.1	Excitation of the Helical Antenna	125
5.2.2	Design of the Antennas	127
5.3	STUDIES ON PLASMA PRODUCTION	129
5.3.1	Effect of Different Feeds	130
5.3.2	Optimization of the Dipole Feed	134
5.3.3	Resonant versus Non-Resonant Configurations	135
5.3.4	Typical Plasma Parameters	137
5.4	PRESSURE VARIATION STUDIES	141
5.5	POWER VARIATION STUDIES	143
5.6	EFFECT OF MAGNETIC FIELD (AT THE ANTENNA REGION)	151
5.7	STUDIES WITH LONG HELICAL TRANSMISSION LINE (LHTL)	154
5.8	CONCLUDING REMARKS	158
6	CONCLUSIONS	159
	APPENDIX I	164
	APPENDIX II	168
	REFERENCES	
	PHOTOGRAPHS OF THE EXPERIMENTAL SYSTEM	