Current electromagnetic research in Canada

Hurd, R. A.

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CURRENT ELECTROMAGNETIC RESEARCH IN CANADA

- R. A. HURD -

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ABSTRACT

Canadian contributions to the theory of antennas, scattering and diffraction, waveguides, plasmas and other media, and mathematical methods are surveyed for the period of January 1972 to June 1973.

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0. INTRODUCTION

0.1 Scope of the work

This paper attempts to survey a certain section of electromagnetic research in Canada from 1 January 1972 to the present (June, 1973). The topics covered include antennas, scattering and diffraction, waveguides, plasmas and other media, mathematical methods. Emphasis has been placed on the solution of problems rather than devices. Within the period, I was able to find some 120 papers (published or in press) and conference talks. In addition, a large number of other projects are listed as being underway. Sometimes a few words of explanation about a paper or project have been included. Clearly, time and space do not allow this for all papers, so I made the selection in a fairly random manner, but it is biased towards antennas, scattering and waveguides - the subjects I am most familiar with.

0.2 Explanation of symbols

Seventeen institutions were responsible for all the work reported. They are identified by initials, as follows:

A	University of Alberta
BC	University of British Columbia
C	Carleton University
CRC	Communications Research Centre, Ottawa
L	Laval University
M	University of Manitoba
McG	McGill University
McM	McMaster University
NB	University of New Brunswick

NRC National Research Council of Canada, Ottawa

O University of Ottawa

Q Queen's University

RCA R.C.A. Limited, Montreal

SRL Sinclair Radio Laboratories, Toronto

T University of Toronto

V University of Victoria

W University of Waterloo.

A typical reference - Smith (1973) W - indicates a paper published in 1973 contributed by the University of Waterloo. Work currently in progress is referred to as being done by Smith (W).

0.3 Apology

It is almost inevitable that there will be errors and omissions in this work. I apologize for them in advance.

1. ANTENNAS

1.1 Single linear antennas

Loading of short monopoles by inserting passive and active elements along the length is of current interest. A single inductive load was considered by Pomerleau and Fournier (1972) L, who found the loading position for maximum efficiency and observed a bandwidth increase of 12%. Active loading was treated by Pelletier et al (1972) L, who report large bandwidth increases. The analysis in the foregoing is by the method of

moments and the results were verified experimentally. Active loading at the base was considered by Furukawa et al (1972) L and improvements in gain and bandwidth were found. Loading by resistors, capacitors, diodes and short perpendicular wires is currently being investigated by Ittipiboon and Hamid (M). Also in progress is a study of active loading of folded dipoles by Yunik, Towaij and Hamid (M); preliminary indications are of a length reduction of 40% together with a gain increase of 3.8 dB over conventional folded dipoles. Disc loading of a tubular dipole and a solid cylindrical dipole are being treated by a new perturbation - moment method by Chow and Seth (W).

The effect of multi-layer dielectric sleeves on the radiation pattern was considered by Towaij and Hamid (1972, 1973a)M. Dielectric and ferrite loadings are also being treated by Shafai (M). An infinitesmal dipole in a plasma column was treated by Yip (1972) McG. Review papers on antennas in plasmas are by Balmain (1972) T and Bachynski (1972) RCA.

An investigation of the sufficiency of certain extended boundary conditions for circularly symmetric antennas is being conducted by Al-Badwaihy (T). A theoretical treatment of the infinite coaxially-fed tubular antenna was presented by Hurd (1973a) NRC.

1.2 Single antennas of other types

The effect of dielectric layers on slot antennas is being investigated. Thus, an axial slot on a coated cylinder was considered by Shafai (1972a) M, and El-Moazzen and Shafai (1973a) M. Conditions for optimum radiated power were derived.

Loading with a moving plasma sheath was also considered by El-Moazzen and Shafai (1973b).

Horn antennas have attracted some attention. Jull (1972) BC calculated an improved expression for the input impedance of an E-plane sectoral horn. Towaij et al (1973) M report more directivity from H-plane sectoral horns with curved apertures. The open-ended parallel-plate waveguide, whose exact solution is known, was treated as a horn by Jull (1973a) BC with the aim of improving the Kirchhoff theory for the gain. Geometrical theory was applied to the pyramidal horn, and new improved gain figures were obtained - Jull (1973b) BC. An improvement on the Schelkunoff expression for E-plane sectoral horn gain is announced by Jull and Allan - (BC/NRC). Jazi (BC) is currently investigating back-lobe reduction through the addition of appendages. An experimental and theoretical study of scalar horns is reported by Legendre (CRC). Markedly greater directivities are obtained by combining an H-plane horn with a Fabry-Perot interferometer - Araujo and MacPhie (W).

A corner reflector loaded by concentric dielectric cylinders at the apex was investigated by Towaij et al (1972) M. Improvements in bandwidth and axial gain are claimed. A theoretical investigation of the gain of finite corner reflectors is reported at A.

A circular waveguide loaded with a dielectric plug has a sharper main beam than the unloaded radiator - Hamid, Towaij and Martens (1972) M. A theoretical study of S/N for electrically small antennas as a function of temperature is by Hoang and Fournier (1972) L.

While it is not our primary purpose to report on antenna design, it is perhaps pertinent to say that many types of antennas - mostly for satellite purposes - are under development by Foldes (RCA) and Breithaupt (CRC). See for example Foldes (1972).

1.3 Arrays

The Galerkin projection method was used to find the current distribution and pattern of Yagi-Uda arrays and the mutual impedance of arbitrarily oriented wire antennas - Silvester and Chan (1972, 1973) McG. The mutual admittance of almost arbitrary collinear antennas was found by Hurd (1972) NRC in terms of elementary functions. A theoretical study of mutual coupling and gain vs. scan angle for a short linear array mounted on a conducting cylinder is in progress at CRC by Goddard and Chinnik. Reactive loading at the centres of the elements of a linear array can be used to realize a tunable Yagi - Seth and Chow (1973) W. Measurements on Yagis are reported by Tilston (SRL), who also is concerned with the location of the phase centres of arrays of corner reflector and linear antennas. Three papers dealing with the design of supersynthesis arrays are by Chow (1971), (1972a,b) W.

A continuing theoretical and experimental investigation of log-periodic antennas is directed by Balmain (T). Swept frequency techniques have proven a powerful tool here. A projective analysis of log-periodics has been made by Chan and Silvester (1973) McG. A log-periodic with conical arms is under study by Iskander and Hamid (M), while log-periodic arrays of V antennas are being considered at McG.

The reduction of blindness in phased arrays due to

element-position errors is the subject of a paper by Zaghloul and MacPhie (1972) W. The measurement of self and mutual admittances of dipoles in arrays is reported by Desjardins and Fournier (1972) L, who used the imaging effect of corner reflectors to simulate the array. A new type of interferometer without R.F. interconnection but with improved S/N was described by MacPhie (1972) W.

1.4 Environmental effects on antennas

The pattern of a dipole in the presence of N small conducting cylinders with N-fold rotational symmetry is being treated theoretically by Tilston (SRL). Also under consideration is the 'complementary' problem with radiators and cylinders interchanged. In another investigation the cylinders are allowed to be large. The pattern of a line source near towers of square and equilateral triangular cross-sections for a fair range of sizes and spacings was found by Shafai (1972b) M. Conformal transformation and numerical methods were used. A similar approach for a line source near a conducting strip is by Shafai and El-Moazzen (1972) M. The effects of a spacecraft on the pattern of a belt array are being computed and modelled by Milne (CRC).

1.5 Optimization and synthesis of antennas

This is a subject of increasing interest. The Dolph-Chebyshev excitation for an equispaced array of non-isotropic identical antennas was computed by Atwood (1972) T, using an iteration procedure. Optimization of the signal-to-noise ratio with constraints on the sidelobe levels or null locations was considered by Cummins and Delisle (1972) L, and in a forthcoming

paper by Delisle and Cummins (1973). Theoretical and experimental results are compared for a 4-element ring array.

A synthesis method for an array of dipoles, in which mutual effects are included, is given in a paper by Sanzgiri and Cummins (1973) L. The problem of synthesising circular and rectangular aperture antennas with aperture power and/or sidelobe levels limited is currently being studied by Sanzgiri, Cummins and Huynh (L). Exact solutions to a number of power-constrained synthesis problems for non-planar apertures were given by Hurd (1973b) NRC.

2. SCATTERING AND DIFFRACTION

2.1 Fundamentals

A large amount of work has been done by Millar (NRC) in locating the singularities of the solution for scattering by two-dimensional objects. In the latest paper - Millar (1973a) - the singularities for an elliptic equation with a boundary curve composed of a union of arcs are explored under very general boundary conditions. Two summary papers are by Millar (1972, 1973c). This theory is of great importance in the numerical treatment of problems, and is still not universally appreciated - Millar (1973b). Currently, efforts are being made to treat 3-dimensional problems.

Relations between interior and exterior diffraction problems for polygonal cylinders are being sought by Iskander and Hamid (M).

2.2 Two-dimensional scattering problems

An E-polarized line source parallel to a conducting

half-plane which is tipped with a dielectric cylinder was treated by separation of variables by Hamid and Towaij (1972) M; its extension to wedges is by Hamid (1973c) M. Shafai and Bhartia (1973) M investigated an E-polarized line source near a conducting cylinder whose cross-section is composed of two intersecting circles of arbitrary radii. A conformal transformation is used to map the cross-section on a circle and the resultant integral equation is solved numerically. The same problem, but with an impedance boundary condition, is being investigated by Bhartia and Hamid (M), who also report work in progress on scattering by cylinders of aerofoil cross-section. Low frequency scattering of a plane wave by a composite dielectric/metal cylinder is being studied by Hurd (NRC). A comparison of two methods of treating radially inhomogeneous circular scatterers, the method of multi-layers and the phase method, was made by Shafai (1972c) M. The phase method was found to be more economical of computer time. Shafai (1973a) has studied the convergence rate of the series for the far-field scattered by a conducting cylinder of triangular cross-section and compared it with that of a circular cylinder. The conclusion drawn was that the rate depends more on the size than on the shape of the scatterer. Scattering by conducting notched circular cylinders was considered by Hunter (1973b) M; the same author has also treated scattering of either TE or TM waves by a moving conducting cylinder of arbitrary cross-section. In Hunter (1973a) the motion is transverse while in Hunter (1973c) it is arbitrary. Results are presented for triangular and square cylinders respectively. An earlier paper employed the geometrical theory of diffraction to treat diffraction by a moving conducting

strip - Hunter (1972b).

The surface current density on arbitrary polygonal cylinders was considered by Hunter (1972a) M for either polarization using the extended boundary condition formulation and numerical techniques. As an example, a triangular prism was treated and the result agrees closely with earlier experiments. Diffraction by two parallel staggered conducting plates is being investigated by Peebles (M) when the edge-to-edge distance is not large. Eventually the case of a dielectric filler will be examined. The exact solution for a line source in a slot in a conducting plane is being examined by Hamid (M) with a view to obtaining a new ray-optical interpretation which does not break down in this degenerate case. A conducting wedge loaded with a dielectric slab of small electrical thickness was treated by Mohsen and Hamid (1973) and the ray-optical diffraction coefficient for the edge derived. A similar problem but with a number of dielectric wedges was examined by Towaij and Hamid (1973b).

The reflection of a TE or TM plane wave pulse from a grounded, lossy dielectric slab was considered by Boerner and Antar (1972) M. For a pulsed gaussian beam there is an analysis by Antar and Boerner (1973).

Low frequency solutions for a line current parallel to the join of two lossy quarter-spaces were given by Weaver and Thomson (1972) V.

2.3 Three-dimensional scattering problems

Scattering by spherically-symmetric radially-stratified objects has been considered by Shafai (1972d) M, who introduced

two new auxiliary functions closely related to the phase and amplitude of the field. It was found that these are easier to compute than traditional functions. The method was applied to Luneberg and Eaton lenses. In a note, Shafai (1972e) showed how the solution is obtainable in terms of elementary functions for a sphere in which ε varies as R^{-1} . A computer programme for the efficient computation of the eigenvalues of the prolate spheroidal wave functions was given by Sinha et al (1973) W. The problem of reducing specular reflection from large surfaces is being studied by Ebbeson (BC). Radiation from a horizontal magnetic dipole in three strata composed of air and two conducting media was analysed in the low frequency case by Ramaswamy et al (1972a), (1973) V. For an arbitrary magnetic source above an N-layer earth there is an analysis by Summers and Weaver (1973) V, valid for low frequencies. Modelling of the coastline response to excitation by low frequency vertical and magnetic dipoles was described by Thomson et al (1972) V. The coupling between collinear, semi-infinite parallel-plate waveguides has been explored by El-Moazzan and Shafai (1973c) M. A similar configuration of circular cylindrical waveguides is also under investigation.

Measurements of the elements of the scattering matrix in the resonance region for spheroids and finite solid cylinders (both metal and dielectric) have been carried out by Allan and McCormick (1972) NRC for axial incidence. Currently the programme is being expanded to larger bodies and arbitrary angle of incidence.

The diffraction of a gaussian beam by a circular aperture was studied by Boulet and Lit (1972) L using the boundary-diffraction-wave theory. A comparison with Kirchhoff theory is made. A method of finding the two characteristic parameters of a gaussian beam by means of two circular diffracting apertures was described by Lit and Boulet (1972) L. Experimental confirmation for Bezner and Artmann's theory of the Goos-Händchen effect has been obtained by Dagg et al (1973) W at 3 cm.

2.4 Inverse scattering

Activity is high in this field in which the aim is to reconstruct objects from measurements of their scattered field. Since in practice only a finite number of measurements can be made, early work has aimed at optimizing these measurements. Combined with rigorous or approximate diffraction theory for perfectly conducting known shapes, these measurements then yield the scatterer's approximate dimensions. Thus Vandenberghe and Boerner (1972a,b) M determined the axes of a small prolate spheroid and of a small elliptic cylinder. The use of geometrical optics was demonstrated for convex cylinders of large radius by Vandenberghe and Boerner (1972c), and for finding the angle of a perfectly conducting wedge by Hamid and Mohsen (1972) M. New boundary conditions suitable for scatterers with impedive surfaces are exhaustively treated by Boerner and Ahluwalia (1972). Their application to imperfectly conducting cylinders and spheres is in three papers by Ahluwalia and Boerner (1973a,b) and Boerner and Das (1973). Current research is directed to the recovery of the shape of a semi-transparent scatterer or numbers of scatterers, and the exploration of relationships between inverse scattering and holography.

The reconstruction of the near-field from far-field data is discussed by Cabayan et al (1973) McG where stability criteria show that it is necessary to take N far-field Fourier coefficients where N depends not only on the errors in the data and quadratures but also upon the radius at which the near-field is required.

3. GUIDED WAVES

3.1 Propagation in waveguide

Propagation in dielectric loaded waveguides has attracted much attention. A paper on the subject was given by Hamid, Towaij and Mohsen (1972) M at the recent general meeting of URSI. The modal structure of a coaxial line, loaded with 3 concentric rings of dielectric, was carefully treated by Lewis and Sarkar (1972) NB, who also found minimum-loss configurations, and explored the phase sensitivity to dimensional variations. The minimum loss was found to be well below the unloaded value. A dielectric-loaded waveguide of particular design is currently being analyzed by Tranquilla (NB). Rectangular waveguides loaded with dielectric layers in the H-plane have been treated in several papers by Bui and Gagné (L). In (1972a) they considered 3 layers and derived the characteristics of the first few modes. Attenuation due to dielectric loss was computed for single slab loading by Bui and Gagné (1972b). Comments on other papers are by Bui and Gagné (1972c).

Surface waves are still of interest. Launching efficiency of the HE_{11} mode on a dielectric tube is the subject of a paper by Yip and Au-Yeung (1973) McG. McRitchie and Beal (1972) Q describe a Yagi-Uda array for launching the dipole mode on a dielectric image line. A six-element array with a launching efficiency of 62% and 18% bandwidth is reported. A survey of the applicability of surface waveguides to communication with ground transport has been carried out by Beal et al (1973) Q. Launching of a surface wave on a plasma column by means of alternately phased rings was analyzed by Ristic (1972) T.

3.2 Waveguide discontinuities

The Green's functions for waveguides of equilateral and right-angled isoceles triangle cross-sections can be computed by imaging - Hamid (1972) M.

A computer programme for the junction capacitance due to coplanar steps in both conductors of a coaxial waveguide was presented by Jurkus (1972) NRC. The basic analysis is due to Whinnery et al in 1944. An experimental study - Hamid (1973a)M - showed that the reflection coefficient of a right angle corner in rectangular waveguide is reduced by dielectric loading of the sharp corners. In like manner it was shown that the reflection coefficient due to a dielectric step discontinuity can be reduced by appropriate dielectric inserts - Hamid (1973b). A numerical method of computing the effect of obstacles in waveguides was given by Wu and Chow (1972) W, and applied to a transverse diaphragm in parallel plate waveguide and to an open-ended parallel plate waveguide. Chow and Wu (1973) W, have applied a "moment method with mixed basis functions" to the same problem. In this approach the field is divided into propagating and evanescent parts which are treated by two different moment methods. Currently it is being applied to waveguide junction problems. The problem of thick diaphragms in rectangular waveguide was treated by Kashyap and Hamid (1972) M using a ray-optics approac

There are many analyses of microstrip configurations to report. Silvester and Benedek (1972a) McG computed the equivalent capacitance of an open circuit, by first deriving a static integral equation and solving it by a projective numerical method. An empirical expression for line lengthening due to an open circuit was given by Jain et al (1972) C. This expression also allows for

finite widths. For the same problem another computed and measured expression is by James and Tse (1972) CRC. The fundamental integral equation for the charge distribution on microstrip was solved by a projective method by Silvester and Benedek (1972b) McG. The capacitance between parallel dielectric-separated rectangular plates was computed by Benedek and Silvester (1972a) McG by solving an integral equation using a projective method and polynomial approximants. Gaps between microstrip sections, and steps in its width, were considered by Benedek and Silvester (1972b), using a polynomial expansion for the charge. Equivalent capacities are given over a considerable range of parameters. The method of finite elements is proposed for the analysis of a planar N-port network by Silvester (1973a). Right angles, T-junctions and crossings were treated - Silvester and Benedek (1973) - by solving integral equations by the method of finite elements. Extensive graphs were presented. The previous McG papers used static approximations; a new evaluation of the inductance of finite strips - Gopinath and Silvester (1973) McG - not only takes the frequency into account but is also a vector problem. It is solved by the Galerkin method. Resonator techniques are currently being used to measure the discontinuity at right-angle bends by Douville (CRC). Coupling between microstrip and rectangular waveguide through a hole in the microstrip ground plane is being studied analytically and experimentally by James (CRC) and Hoefer (O). Measurements of the elements of the scattering matrix for microstrip junctions and obstacles have been made by Schellenberg and Beal (1972) Q. The reflection from a semi-annular metal obstacle over a dielectric image line was considered theoretically and experimentally by Mahmoud and Beal (1972) Q. Scattering from a small inhomogeneity in a two-dielectric circular surface-waveguide was treated by Yip et al (1973) McG who computed the radiated power loss. A mode-matching approach was used by McRitchie et al (1973) BC to find the equivalent circuit of a symmetrical iris in a dielectric loaded rectangular waveguide.

The coupling coefficient for two identical cavities joined by a small aperture in a thick common wall was evaluated by McDonald (1972) T using the variational technique. Resonant circular-symmetric cavities which are frequency insensitive to length changes were analyzed by Aboul-Atta and Tomchuk (1972) M.

4. PLASMAS AND OTHER MEDIA

Some plasma-antenna papers have already been mentioned in section 1. Other aspects of plasmas are being studied intensively at L, RCA, T & V. The admittance ofa spherical probe in a warm electron-ion plasma was derived by Homonick and Balmain (1973) T, who report a shallow dip in the admittance just below the ion frequency. A slight dip in the capacitance near the ion frequency was also the theoretical and experimental finding of Oliver and Clements (1973) V. The capacitance of the plasma sheath surrounding a Langmuir probe was measured by Oliver and Clements (1972) V. At RCA current research is directed toward loss of coherence of e.m. waves in turbulent plasmas of fairly high electon density. A new technique due to Ghosh, Shkarofsky and Almay - involving measurements at two frequencies - allows instantaneous fields to be measured. Previously, the backscatter from a turbulent plasma had been computed and measured by Shkarofsky et al (1972) RCA. Non-linear effects on the sheath admittance of a short wire antenna in the ionosphere was computed at very low frequencies by Shkarofsky (1972). Pulse distortion has been measured when there is strong interaction between wave and plasma by Bachynski and Gibbs (1972b) RCA. This is for the case when the

wave amplitude significantly alters the plasma properties, and was investigated theoretically and experimentally in an earlier paper (1972a).

At L, non-linear effects, the plasma-conductor junction and diagnostics by microwaves are presently being studied by Gagné and Cao Lieu. An experimental investigation of electrostatic probes in r.f. discharge plasmas can be found in the paper by Gagné and Cantin (1972) L. The analysis of probe/scatterer interaction is the subject of a paper by Howarth (1973) McG. Theoretical studies of propagation in a non-linear dispersive medium are being carried out by Small (NB).

5. MATHEMATICAL METHODS

Methods based on the computer completely dominate in the solution of field problems. Fortunately, the old brute force approach has been largely replaced by analytical-computer methods, in which the aim is to cut computer time either by new techniques or increased preparatory analyses - or both. At M considerable emphasis is being given to finding functionals which are stationary with respect to variations of the desired unknown u, which is then expanded in a finite series of known functions with unknown amplitudes, the Rayleigh-Ritz procedure applied, and the resulting linear set of equations solved. This is the traditional variational approach applied backwards, but it sometimes happens that the functional is the desired quantity. The method is applied to the Poisson equation under mixed boundary conditions by Hazel and Wexler (1972). Good agreement between exact and approximate solutions for a square is obtained. In a

sequel paper - Richards and Wexler (1972), the method is refined by the addition of the finite element method. Curved boundaries can be handled, and examples are given. The finite element method (where the region of interest is subdivided into areas - the elements - and different expansions and/or methods applied in each) is explored for open regions by McDonald and Wexler (1972). In this paper it is proposed to treat source regions, regions of inhomogeneity and anisotropy by differential techniques and the remainder by formulating an integral equation.

At McM minimax approaches to non-linear optimization have been pursued. Two papers are by Bandler and Srinivasan (1972) and Bandler et al (1972). While directed toward network optimization and hence outside our domain, they are mentioned here for their possible application to antenna problems. A paper showing how the computing time for the finite element method can be reduced was presented by Torre and Kinser (1973) McM.

At McG the finite element element method using high order polynomial trial functions has been pursued. In Silvester (1972), the 3 dimensional Helmholtz equation was treated using tetrahedral elements. It turns out that large amounts of analysis can be done once and for all, so that the method is quite economical.

The axisymmetric scalar Helmholtz equation was considered by Silvester and Konrad (1973) and applied to the potential distribution near a dielectric bead in coaxial waveguide. The method is currently under extension to vector fields, and anisotropic media. In the axisymmetric case it leads to a

"generalized Bessel equation". In these papers, variational forms are employed.

At W a modified moment method has been invented in which the field is split into distinct parts and different basis functions used in each - Chow and Wu (1973).

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