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This final report covers the period July 1, 1991 through April 30, 1997. The unifying theme of the research undertaken during the course of this contract is the design of monolithic antennas suitable for millimeter-wave operation, and also certain aspects of feed network design at millimeter-wave frequencies. The main focus of the antenna design projects was the investigation of planar leaky-wave antennas consisting of either dielectric layers or periodic screens. These antennas offer the advantages of simplicity and efficiency at millimeter-wave frequencies. Several different types of leaky-wave antennas were developed and characterized, and shown to be very useful at millimeter-wave frequencies. Other useful types of antennas that are suitable for either microwave or millimeter-wave operation arose from this research, including new types of antennas that have less surface-wave excitation (reduced surface wave antennas), and hence less mutual coupling and spurious radiation. The part of the research that pertained to feed network design focused on exploring the suitability of using conventional printed-circuit transmission lines (stripline and microstrip) for millimeter-wave operation, where the electrical substrate thickness may be large. In particular, the existence of leaky-modes on these printed-circuit lines, and their excitation by practical feeds, was examined.

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Monolithic Millimeter-Wave Radiating Systems and Feed Networks

FINAL REPORT

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October 6, 1997

U.S. ARMY RESEARCH OFFICE

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FOREWORD

This final report covers the period July 1, 1991 through April 30, 1997. There were several projects that were initiated at the beginning of this contract, and others at were originated during the course of this contract. These projects have been described in detail in the previous interim progress reports that have been written. These detailed descriptions are not repeated here. Instead, a brief executive summary of the main projects, highlighting their significance and relevance to the research contract, are summarized below, along with a discussion of the main research accomplishments.

The unifying theme of the research undertaken during the course of this contract is the design of monolithic antennas suitable for millimeter-wave operation, and also certain aspects of feed network design at millimeter-wave frequencies. The main focus of the antenna design projects was the investigation of planar leaky-wave antennas consisting of either dielectric layers or periodic screens. These antennas offer the advantages of simplicity and efficiency at millimeter-wave frequencies. Several different types of leaky-wave antennas were developed and characterized, and shown to be very useful at millimeter-wave frequencies. For example, a simple dielectric leaky-wave antenna operating at 62.2 GHz was demonstrated. Accurate analysis techniques were developed for all of these antennas, and results demonstrated good agreement between calculated and measured patterns. Other useful types of antennas that are suitable for either microwave or millimeter-wave operation arose from this research, including new types of antennas that have less surface-wave excitation (reduced surface wave antennas), and hence less mutual coupling and spurious radiation.

The part of the research that pertained to feed network design focused on exploring the suitability of using conventional printed-circuit transmission lines (stripline and microstrip) for millimeter-wave operation, where the electrical substrate thickness may be large. In particular, the existence of leaky-modes on these printed-circuit lines, and their excitation by practical feeds, was examined. It was shown for the first time that a dominant leaky mode exists on microstrip line at high frequencies, and that air gaps in common stripline can result in spurious performance due to the excitation of a dominant leaky mode. Both theoretical calculations and measurements were used to confirm these predictions.

A summary of these topics, and others, is given in the following report.

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RESEARCH STATEMENT

The projects that were supported by this research contract all pertain, directly or indirectly, to the subject of *Monolithic Millimeter-Wave Radiating Systems and Feed Networks*. One of the central themes in this research has been the analysis and design of leaky-wave antennas that are suitable for efficient operation at millimeter-wave frequencies. Leaky-wave antennas have the natural advantages of simplicity and efficiency, since they do not require a complicated feed network such as a corporate feed to achieve highly directive patterns. These antennas may be excited with a simple source, such as a dipole or a waveguide feed. The physical structure itself then acts as the radiating aperture, to produce narrow-beam patterns.

The research topics have included the characterization and design of *two-dimensional* leaky wave antennas, in which a planar guiding surface is used to support the propagation of a cylindrical leaky wave that emanates from the source. The planar guiding surface is placed over a grounded dielectric slab, and the region between the ground plane and the guiding surface acts as a leaky parallel-plate waveguide. The beam angle can be easily controlled by adjusting the thickness of the substrate, while the attenuation constant, and hence the beamwidth, can be adjusted by varying the parameters of the guiding surface. Several types of guiding structures were investigated. The simplest of these uses a dielectric layer as the guiding surface. In particular, the guiding surface is a high-permittivity superstrate layer placed over the substrate, whose thickness is approximately one-quarter dielectric wavelength. The permittivity of the superstrate layer controls the leakage constant. Another guiding structure that was investigated is a periodic array of metallic patches (frequency selective surface). In this case the patch dimensions are used to directly control the leakage constant. A novel guiding structure that was also investigated is a thin film of high-temperature superconductor, whose thickness is small relative to a penetration depth. For this structure the ground plane is also made of superconducting material, resulting in very low conductive losses.

In addition to the two-dimensional leaky-wave antennas that were studied, one-dimensional leaky wave antennas were also investigated. These leaky-wave antennas are practically realized by replacing one of the narrow walls of a rectangular waveguide with a guiding structure. The broad walls of the waveguide may also be extended to create a baffle, which allows for better polarization purity and extra design flexibility in the control of the attenuation constant. Two types of guiding structures were investigated, a high-permittivity dielectric layer (the one-dimensional counter-part of the two-dimensional dielectric layer leaky-wave antenna), and a periodic strip grating. In both cases, the research was aimed at optimizing the design to improve the shape of the pattern, and also calculating the pattern for a realistic structure, in which the aperture is assumed to be of finite length and the source excitation is accounted for.

In additional to the leaky-wave antennas studied under this contract, microstrip antennas were also studied. In particular, a new class of microstrip antennas, termed the reduced surface wave (RSW) microstrip antennas, was developed under this contract,. The RSW microstrip antennas excite less surface and lateral waves than do conventional microstrip antennas, resulting in reduced mutual coupling and scan blindness, and less pattern degradation due to diffraction of the surface and lateral-wave fields from edges of a finite ground plane or substrate. After the initial design was proposed and verified, the concept was extended to make *dual-band* RSW antennas, which have reduced surface wave properties at two different bands, e.g. transmit and receive bands.

Another research topic that was investigated under this contract was the characterization of leaky modes on printed-circuit lines. In recent years, the existence of *dominant leaky modes* on printed-circuit lines has become well established. A dominant leaky mode is one that has a current on the conducting strip that resembles that of the bound quasi-TEM mode, and may therefore be easily excited by a customary feed (such as a probe or end-launch connector). During the course of this research dominant leaky modes were discovered on two practical structures: stripline with an air-gap above the strip (which may inadvertently occur during manufacturing of the stripline), and microstrip line at high frequencies, where the substrate thickness is about one-tenth of a dielectric wavelength or more. The existence of these leaky modes has important implications for the design of feed networks at millimeter-wave frequencies, where leakage loss may become severe and result in significant spurious performance. The properties of the leaky modes were studied for an infinite line to ascertain the fundamental propagation characteristics. The nature of the leakage fields from a semi-infinite line was then examined, to study the properties of the leakage field when the leaky mode is launched by a practical feed.

SUMMARY OF RESEARCH RESULTS

The main research projects that were supported in whole or in part by the present research contract are listed below. The reference numbers in this description correspond to the publications list that immediately follows in the next section of this report. Additional details may be found in the references, and the previous interim progress reports.

1. A novel leaky-wave antenna suitable for millimeter-wave applications was developed. This antenna consists of a two-dimensional frequency selective surface, consisting of an array of metallic patches, printed on a grounded dielectric substrate [1]. The structure acts as a leaky parallel-plate waveguide that supports leaky modes, and hence acts as a leaky-wave antenna. The substrate thickness controls the beam angle, and either conical beams at a specified angle or pencil beams at broadside can be easily produced. The structure is easily excited by a simple source, such as a dipole inside the substrate or a waveguide feed from below the substrate. An thorough analysis of this structure was performed to determine the properties of the leaky modes on the structure, and from this, useful design information was obtained. A leaky-wave analysis was used to predict the radiation patterns of practical structures with a finite-size aperture, terminated with absorber. Experimental patterns that were measured showed good agreement with the predicted patterns. This project has been finished, although the results have not yet been disseminated in publications (in preparation).

2. Research was conducted into the characteristics of leaky-wave antennas using dielectric layers[2]-[3]. The dielectric leaky-wave antenna structure consists of a grounded substrate with a top superstrate, where the permittivity of the superstrate is higher than that of the substrate. Such antennas are very simple to construct, and offer the possibility of very efficient, low-loss antennas, since a minimal amount of metal is used in the construction. As with the periodic leaky-wave antenna mentioned above, this structure may be easily designed to obtain either conical beams or broadside pencil beams. In this project, a thorough characterization of one-dimensional leaky-wave propagation on dielectric leaky-wave structures was first performed [2]. This investigation revealed the basic properties of the leaky modes, and useful approximate design formulas were obtained. An efficient and accurate method for predicting the radiation pattern of a finite-size aperture was developed and tested. After this work was completed, the analysis was extended to a practical two-dimensional structure, which may be easily excited by a dipole or waveguide feed [3]. Efficient formulas for calculating the radiation patterns for practical structures with a finite-radius aperture terminated with absorber were developed. An experimental millimeter-wave antenna was constructed at 62.2 GHz, using a ceramic superstrate material. The measured patterns showed very good agreement with the calculated patterns. This research project was conducted in collaboration with a research group at the Technical University of Munich, in Germany, and with Prof. Arthur A. Oliner of the Polytechnic University.

3. A practical one-dimensional leaky-wave antenna structure was studied in detail, the dielectric-inset stub-loaded metal strip grating antenna [4]-[6]. This structure consists of a rectangular waveguide that is filled with a dielectric material, with one of the narrow walls replaced by a

metal-strip grating. The two broad walls are then extended beyond the plane of the grating to create a baffle, which allows for better polarization purity and increased design flexibility, since the baffle height can be used to control the attenuation constant. This structure was previously introduced by Guglielmi and Oliner. The physical nature of the leaky modes on this structure were first studied in detail. This resulted in a new understanding of the behavior of the modes that exist on a general open periodic structure, and in particular, how the physical significance of the leaky modes changes as the beam is scanned to forward endfire (the spectral-gap region). A rigorous multimode network analysis technique was used to characterize the grating in an efficient manner for the analysis of the grating structure. Formulas were then derived for the radiation pattern of this antenna when fed by a practical feed, consisting of a coaxial-fed probe that extends from one broad wall to the other. The probe may be positioned longitudinally at the center of structure to obtain a broadside beam, or a quarter-wavelength away from one short-circuited end to obtain a scanned beam. The analysis was extended to allow for a finite-length aperture, terminated by absorber. Measured patterns were taken which demonstrated good agreement with calculated ones. The results from the spectral-gap investigation are given in [4]. The results from the pattern calculation have not yet been published (in preparation). This project was performed in collaboration with Prof. Arthur A. Oliner of the Polytechnic University.

4. A novel type of leaky-wave antenna using a high-temperature superconducting thin film was developed and analyzed [7]-[8]. This leaky-wave antenna uses a thin film of superconducting material to replace the metallic grating or the dielectric layer of the previous leaky-wave antennas. The thin film is made small compared to a penetration depth, so that appreciable radiation leakage can occur through the film. Because the ground plane is also made of superconducting material, conductive losses can be made very small. An analysis of this structure has shown that highly directive patterns can be obtained with higher efficiencies than is possible with leaky-wave antennas composed of normal metal ground planes. Formulas were derived for the leakage constant as a function of the film parameters, to show what ranges of beam widths are obtainable with this structure with presently available films. The construction of an experimental antenna is planned, although this will take place after the present contract period. The results have not yet been disseminated in publication form (in preparation). This project has been performed in collaboration with the Texas Center for Superconductivity at the University of Houston.

5. An investigation into dominant leaky-mode propagation on printed-circuit structures was conducted. (A dominant leaky mode is defined as one that has a current distribution on the conducting strip that is quasi-TEM in nature, thereby resembling the conventional bound mode.) These structures include multilayer stripline [9], [10] and microstrip line [11]. These transmission lines are commonly used to construct feed systems for planar antenna arrays. It was discovered that a leaky mode exists on stripline if a small air gap is introduced above the conducting strip [9]. The properties of this leaky mode were explored, and it was concluded that the excitation of this leaky mode was responsible for the spurious performance that has often been reported previously and attributed to the existence of air gaps in the stripline circuit. The existence of a dominant leaky mode on microstrip line was also discovered for the first time [11]. This leaky mode exists at higher frequencies, where the substrate thickness is typically greater than about one-tenth of a wavelength in the substrate. This has important

implications for millimeter-wave design. The spurious performance that can result from excitation of this leaky mode on microstrip line was demonstrated experimentally. Methods for eliminating the leaky mode were also studied, in which superstrate layers were used to raise the propagation constant of the propagating mode relative to that of the fundamental substrate surface-wave mode. This project was performed in collaboration with Prof. Arthur A. Oliner of the Polytechnic University.

6. As a continuation of the above project, the leakage field from a semi-infinite printed-circuit transmission lines was studied [12], [13]. The leakage from an infinite line is the most commonly studied form of leakage. However, all practical printed-circuit lines have a finite beginning, where the leaky mode is launched. A semi-infinite line is a good model for a leaky mode that is launched at the beginning of a printed-circuit line. Asymptotic formulas were derived that accurately predict the leakage field as the observation distance down the line from the beginning of the strip increases. These formulas, and the numerical results that were obtained from them, illustrate how the leakage field behaves in the vicinity of a leaky line, and thus show how a leaky mode on a practical printed-circuit line will interact with surrounding circuit components to produce cross-talk. This project is on going, and is being performed in collaboration with Prof. Arthur A. Oliner of the Polytechnic University.

7. A new class of microstrip antennas was developed, the reduced surface wave (RSW) antenna [14]. A reduced surface wave microstrip antenna is one that excites less surface waves than a conventional microstrip antenna. The RSW antenna introduced in [14] is a modification of a circular patch antenna. The basic operating principal is based on the idea that a ring of magnetic current that varies as $\cos\phi$ will not excite the fundamental TM_0 surface wave if the radius is chosen to be a critical value. One form of the RSW antenna is an annular ring that has the inner boundary short-circuited. The outer radius is chosen to be the critical value necessary to avoid excitation of the TM_0 surface wave. The inner radius of the ring is then chosen to make the antenna resonant at the design frequency. The patch has a single radiating edge, which has the critical radius to avoid excitation of the surface wave. The magnetic current of the resonant TM_{11} patch mode, therefore, does not excite any surface-wave field. The patch only excites a small amount of surface-wave field due to the presence of higher-order modes in the patch cavity, as well as the fringing fields of the TM_{11} mode. One consequence of the reduced surface excitation is that the fields inside the substrate are smaller and decay much faster with distance from the RSW antenna than they would from a conventional patch antenna. This in turn should lead to reduced mutual coupling in an array environment, which would lead to reduced scan blindness and variation of input impedance with scan angle. Calculations have been made to predict the actual surface-wave field due to the RSW antenna [15], thus accounting for the small amount of surface-wave excitation due to higher-order modes and the fringing fields of the dominant mode. The reduced field level in the substrate has been verified experimentally, and experiments are now in progress to verify the reduced mutual coupling in an array environment. Future work will also involve the calculation of the scan impedance of an array of reduced surface wave antennas. Another benefit of the RSW antennas is that the diffraction from the edges of the ground plane is reduced, resulting in less back radiation and forward scattering, so that the pattern is improved. This has been verified experimentally. The one disadvantage of the RSW antenna

relative to a conventional patch antenna is that the physical size of the RSW antenna is larger. Future work will address potential size reduction of these antennas through design modifications.

8. The reduced surface wave antenna concept was extended to make a dual-band reduced surface wave antenna [16],[17]. This extension uses an elliptical inner boundary (the short-circuit boundary) instead of a circular one. The elliptical boundary splits two degenerate orthogonal modes of the single-band RSW antenna into two separate bands, one corresponding to a mode that varies as $\cos\phi$ and the other varying as $\sin\phi$. The band separation depends on the ellipticity ratio (ratio of major to minor axis) of the elliptical boundary. An analytical formula for the band separation was derived using a perturbational formula, assuming a small deformation of the circular boundary to the elliptical one. Measurements of the band separation for different ellipticity ratios have been compared with the calculated separation, and the agreement has been found to be quite good for small ellipticity ratios. The formula for band separation also allows for the design of a circularly-polarized (CP) reduced surface wave antenna. In this case the feed is placed on a 45 degree diagonal, and the band separation is chosen according to the bandwidth of the antenna to give CP. The design and construction of CP reduced surface wave antennas will be the subject of future work.

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"Leakage Fields from Planar Semi-Infinite Transmission Lines", F. J. Villegas, D. R. Jackson, and J. T. Williams, IEEE MTT-S Intl. Microwave Symposium, San Francisco, CA, June 1996 (Symp. Digest, pp. 183-186).

"Investigation of Leakage Fields from Leaky Modes on Semi-Infinite Planar Transmission Lines", F. J. Villegas, D. R. Jackson, J. T. Williams, and A. A. Oliner, PIERS Symp., Innsbruck, Austria, July 1996 (Conf. Proc., p. 55).

"Leaky Modes on Printed Circuit Lines", D. R. Jackson, J. T. Williams, and A. A. Oliner, PIERS Symp., Innsbruck, Austria, July 1996 (Conf. Proc., p. 415).

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"Applications of High Temperature Superconductors in Antenna Systems", Intl. Symp. on Antennas and Propagation S. A. Long and J. T. Williams, Chiba , Japan, Sept. 1996.

"The Nature of the Spectral Gap for Leaky Waves on a Periodic Strip Grating Structure", S. Majumder, D. R. Jackson, M. Guglielmi, and A. A. Oliner, IEEE MTT-S Intl. Microwave Symposium, Denver, CO, June 1997 (Symp. Digest, pp. 479-482).

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"The Excitation of Leaky Modes on Microstrip Line", F. Mesa, C. Di Nallo, and D. R. Jackson, PIERS Symp., Cambridge, MA, July 1997 (Conf. Proc., p. 626).

"The Physical Significance of Leaky Modes on a Periodic Strip Grating Structure", S. Majumder, D. R. Jackson, and M. Guglielmi, PIERS Symp., Cambridge, MA, July 1997 (Conf. Proc., p. 767).

"Radiation Characteristics of One-Dimensional Periodic Leaky-Wave Antennas", S. Majumder and D. R. Jackson, IEEE AP-S/URSI Intl. Symp., Montreal, CA, July 1997 (AP-S Digest, pp. 452-455).

"Theory of Line-Source Radiation from a Metal-Strip Grating Dielectric-Slab Structure", H. Y. Yang and D. R. Jackson, IEEE AP-S/URSI Intl. Symp., Montreal, CA, July 1997 (AP-S Digest, pp. 1740-1743).

"Dual-Band Reduced Surface Wave Antennas", V. Davis, J. T. Williams, D. R. Jackson, and S. A. Long, Intl. Conf. On Electromagnetics in Advanced Applications (ICEEA), Torino, Italy, Sept. 1997 (to appear).

INVITED SEMINARS (* denotes speaker)

"Microstrip Antennas: Overview of Analysis, Properties, and New Effects", *D. R. Jackson, J. T. Williams, and S. A. Long, Dallas, TX (sponsored by IEEE), Nov. 11, 1993.

"Microstrip Antennas: Overview of Analysis, Properties, and New Effects", *D. R. Jackson, J. T. Williams, and S. A. Long, Harris Corp., Melbourne, FL, Aug. 5, 1994.

"An Overview of the Research at the College of Engineering at the University of Houston", Chiba University ,*S. A. Long, Oct. 1996.

“Leaky Waves on Printed-Circuit Structures”, *D. R. Jackson, J. T. Williams, and A. A. Oliner, Chiba University, Chiba, Japan, Oct. 2, 1996.

“Microstrip Antennas: CAD and Methods to Improve Performance”, *D. R. Jackson, J. T. Williams, and S. A. Long”, Chiba University, Chiba, Japan, Oct. 3, 1996.

SCIENTIFIC PERSONNEL

FACULTY:

David R. Jackson
Stuart A. Long
Jeffery T. Williams

GRADUATE STUDENTS:

Vickie Davis (Ph.D.)
Antonio Ip (Ph.D.)
Sue Jiang (Ph.D.)
Swati Majumder (Ph.D.)
David Nghiem (Ph.D.)
Pavan Potharazu (M.S.)
Frank Villegas (M.S.)

DEGREES AWARDED:

Pavan Potharazu, "Leaky-Wave Propagation Characteristics of Strip-Grating and EMC Dipole Array", MSEE, 1991.

David Nghiem, "An Investigation of Dominant-Mode Leakage on Multiple-Layered Stripline and Microstrip Structures", Ph.D., 1993.

Frank J. Villegas, "An Investigation of the Leakage Fields from Planar Semi-Infinite Transmission Lines", MSEE, 1995.

Swati Majumder, "Leaky-Wave Propagation and Radiation for a Periodic Strip-Grating Leaky-Wave Antenna" (tentative title), Ph.D. expected Dec. 1997.

Antonio Ip, "Analysis and Design of a Two-Dimensional Leaky-Wave Antenna using a Periodic Array of Metal Patches" (tentative title), Ph.D. expected June 1998.

Vickie Davis, "Analysis and Design of Reduced Surface-Wave Antennas" (tentative title), Ph.D. expected June 1998.

HONORS AND AWARDS

- In 1991, Stuart A. Long was elected as Fellow of the IEEE, "for contributions to the development of microstrip and dielectric resonator antennas", 1991.
- In 1991, Stuart A. Long received the University Teaching Excellence Award.
- In 1991, Stuart A. Long was the Runner-up for the Kittinger/Halliburton Award as Outstanding Teacher in the College of Engineering.
- In 1991, Jeffery T. Williams was recognized as an Outstanding Engineering Educator by the Cullen College of Engineering.
- In 1991, Jeffery T. Williams was the runner-up for IEEE/HKN Outstanding Electrical Engineering Instructor Award.
- In 1991, Jeffery T. Williams was nominated for the Distinguished Young Electrical Engineering Teacher Award by the local Eta Kappa Nu Chapter.
- David R. Jackson received the Young Faculty Research Award from the College of Engineering, University of Houston, 1991.
- In 1992, Stuart A. Long began a three-year term as an IEEE Antennas and Propagation Society Distinguished Lecturer (1992-1994).
- In 1992, Stuart A. Long received the Engineering Alumni Association Distinguished Engineering Faculty Award.
- In 1992, Jeffery T. Williams received the Cullen College of Engineering Young Faculty Research Award.
- In 1993, Jeffery T. Williams received the Greenwood Award (Faculty Achievement Award), from the City of Houston.
- In 1993, Jeffery T. Williams received the Kittinger/Halliburton Award as Outstanding Teacher in the Cullen College of Engineering.
- In 1993, Jeffery T. Williams received the IEEE/HKN Outstanding Electrical Engineering Instructor Award.
- In 1993, David R. Jackson received the Greenwood Award (Faculty Recognition Award) from the City of Houston.
- In 1993, Stuart A. Long gave the keynote address on *Applications of High-Temperature Superconductors to* Antennas *Systems* at the ANTEM Symposium in Ottawa, Ontario, Canada, in August 1994.

- In 1994, Stuart A. Long received the IEEE-HKN award for Outstanding Electrical Engineering Teacher.

- In 1994, Jeffery T. Williams was a Finalist for the University of Houston Outstanding Teacher Award.

- In 1994, Jeffery T. Williams was Recognized as an Outstanding Engineering Educator by the Cullen College of Engineering.

- In 1995, Dr. Stuart A. Long served as Vice-President of the IEEE Antennas and Propagation Society.

- In 1995, Stuart A. Long received the College of Engineering Senior Research Award from the University of Houston.

- In 1995, Jeffery T. Williams was recognized as an Outstanding Engineering Educator by the Cullen College of Engineering.

- In 1995, Dr. David R. Jackson became a Senior Member of the IEEE.

- Stuart A. Long was President of the IEEE Antennas and Propagation Society during 1996.

- Stuart A. Long was invited to give the keynote address for the Intl. Symposium on Antennas and Propagation, at Chiba University, in Sept. 1996. The title of his presentation was "Applications of High Temperature Superconductors in Antenna Systems".

- David R. Jackson received a University-wide Excellence in Research and Scholarship Award at the Associate Professor level, University of Houston, 1997.

- David R. Jackson was elected as Secretary, U. S. Commission B of URSI (beginning Jan. 1, 1997).

- David R. Jackson was elected as a member of the IEEE AP-S ADCOM Committee (beginning Jan. 1, 1997).

INVENTIONS

No patent disclosures were filed from the results of this research. Instead, public dissemination of the research results was made by direct publication of the results from this research. The main inventions that resulted from this research are listed below.

- A class of leaky-wave antennas for millimeter-wave frequencies, consisting of dielectric layers or a periodic screen on a grounded substrate, fed by a probe or waveguide.
- A novel type of microstrip antenna, called the reduced surface wave (RSW) antenna, which excited less surface waves than a conventional microstrip antenna, resulting in less mutual coupling and spurious radiation.
- A dual-band version of the RSW microstrip antenna.

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[2] "Radiation from One-Dimensional Dielectric Leaky-Wave Antennas", H. Ostner, J. Detlefsen, and D. R. Jackson, IEEE Trans. Antennas and Propagation, Vol. 43, pp. 331-339, April 1995.

[3] "Radiation from Dielectric Leaky-Wave Antennas with Circular and Rectangular Apertures", H. Ostner, J. Detlefsen, D. R. Jackson, and E. Schmidhammer, Electromagnetics (accepted for publication).

[4] "Spectral Gaps for Leaky Waves on a Periodic Structure", S. Majumder, D. R. Jackson, A. A. Oliner, and M. Guglielmi, IEEE Trans. Microwave Theory and Techniques (accepted for publication).

[5] "Radiation from One-Dimensional Periodic Leaky-Wave Antennas", S. Majumder, D. R. Jackson, and M. Guglielmi, IEEE AP-S/URSI Intl. Symp., Baltimore, MD, July 1996 (URSI Abstracts, p. 324).

[6] "The Nature of the Spectral Gap for Leaky Waves on a Periodic Strip Grating Structure", S Majumder, D. R. Jackson, M. Guglielmi, and A. A. Oliner, IEEE MTT-S Intl. Microwave Symposium, Denver, CO, June 1997 (Symp. Digest, pp. 479-482).

[7] "A High-Temperature Superconducting Leaky-Wave Antenna", J. Poosarla, J. T. Williams, and D. R. Jackson, IEEE AP-S/URSI Intl. Symp., Seattle, WA, June 1994 (URSI Abstract, p. 103).

[8] "A Monolithic High-Gain Superconducting Antenna", J. Poosarla, J. T. Williams, and D. R. Jackson, URSI National Radio Science Meeting, Boulder, CO, Jan. 1995 (Abstracts, p. 192).

[9] "Leakage of Dominant Mode on Stripline with a Small Air Gap", D. Nghiem, J. T. Williams, D. R. Jackson, and A. A. Oliner, IEEE Trans. Microwave Theory and Techniques, Vol. 43, pp. 2549-2556, Nov. 1995.

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[13] "Investigation of Leakage Fields from Leaky Modes on Semi-Infinite Planar Transmission Lines", F. J. Villegas, D. R. Jackson, J. T. Williams, and A. A. Oliner, PIERS Symp., Innsbruck, Austria, July 1996 (Conf. Proc., p. 55).

[14] "Microstrip Patch Designs That Do Not Excite Surface Waves", D. R. Jackson, J. T. Williams, A. K. Bhattacharyya, R. Smith, S. J. Buchheit, and S. A. Long), IEEE Trans. Antennas and Propagation, Vol. 41, pp. 1026-1037, Aug. 1993.

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[17] "Dual-Band Reduced Surface Wave Antennas", V. Davis, J. T. Williams, D. R. Jackson, and S. A. Long, Intl. Conf. On Electromagnetics in Advanced Applications (ICEEA), Torino, Italy, Sept. 1997 (to appear).