Section 3 Electromagnetics

Chapter 1 Electromagnetic Wave Theory and Applications

Chapter 1. Electromagnetic Wave Theory and Applications

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1.1 SIR-C Polarimetric Radar Image Simulation and Interpretation

Sponsor

National Aeronautics and Space Administration
Contract 958461

Project Staff

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This project investigates the use of spaceborne polarimetric radar measurements for monitoring, mapping, and retrieving the aboveground vegetation biomass. Fully polarimetric radar data obtained from the SIR-C/XSAR missions in April and October 1994 over the Landes Forest in Southwestern France have been analyzed in detail.

In this work, we have collaborated closely with Dr. T. Le Toan's research group at the Center d'Etudes Spatiale de la Biosphere (CESBIO) of France. During the various flights of SIR-C/XSAR over the test site, extensive ground truth data has been collected by Dr. Le Toan's team. The data consists of an updated biomass map, which provides the location and ages of more than 50 stands of maritime pines, as well as the statistical information about the densities and sizes of trees and branches. In addition, a clear-cut map with some ground truth measurements including soil moisture and surface profiles is also available. These valuable descriptions provide the key input parameters for the theoretical pine forest scattering model. The acquired SIR-C data has been compared with the previous AIRSAR campaign (L- and C-band, fully

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polarimetric, 40 degrees to 50 degrees), ERS-1 data (C-band, VV, 23 degrees), and JERS-1 data (L-band, HH, 35 degrees) to assure the consistency of measurement.

In the investigation of the application of SIR-C data to vegetated terrain classification and biomass inversion, the measured backscattering coefficients, the derived complex correlation coefficient of HH and VV polarizations as well as the ratio between cross- and co-polarization ratio, are fully utilized. A validated pine forest scattering model, which is based on radiative transfer theory with the specific branching structure of a pine tree taken into account, is used to interpret the SIR-C/XSAR polarimetric backscattering measurements from the Landes forest. The cross-polarization backscattering coefficients at L-band and the correlation between HH and VV backscattering returns at both L- and C-band are found to be most useful quanitites for biomass retrieval. Bayesian classifications using data with known ground truth and theoretical simulation are applied to classify the forest for biomass up to 50 tons per hectare with the available data at this time (26 degrees of incident). With the use of the pine forest scattering model, biomass inversion has been shown to be feasible over a wider biomass range (up to 100 tons per hectare) for angles of incidence around 45 degrees. In addition to the analysis of SIR-C/XSAR data, we have refined our forest scattering model by taking into account the double scattering mechanism between trunk and branches which shows more effect on the cross-polarized backscattering return. We have also studied the collective scattering and absorption effects of clustered objects like the branches and leaves in a vegetative canopy. A new approach for studying the polarimetric response of various types of forest is also developed by using the L-systems technique to generate different kinds of plants.

1.2 Polarimetric Passive Remote Sensing

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This project investigates the application of fully polarimetric passive remote sensing techiques to the detection of sea surface wind direction using air-borne or space-borne radiometers. The primary objectives are (1) to obtain a better understanding of how the third Stokes brightness parameter U is related to ocean wind direction, and (2) to develop a rough surface scattering model for realistic ocean surfaces that is required for the study of U. This brightness parameter U, which is not measured in conventional passive remote sensing, has recently been shown to respond to the azimuthal anisotropy of the observed medium and thus give information on the ocean wind direction. The calculation of the polarimetric brightness temperature of the ocean requires the use of rough surface scattering theory and a statistical model of the ocean surface. Our approach has been to use exact numerical methods, such as the extended boundary condition method and the method of moments, to insure accurate calculation of the polarimetric brightness temperature. Experimental verification of our models also plays an important role in the project. Through cooperation with U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) and the Jet Propulsion Laboratory (JPL), experimental measurements were performed of periodic water surface polarimetric brightness temperature, and the results were found to be in good agreement with the theoretical predictions.

This project has established that U exists for a one-dimensional periodic surface and that it gives more information than conventional single polarization measurements at a single azimuthal angle. Values of U exceeding 30 K were measured at X and Ku band from a periodic water surface, and shown to indicate the azimuthal angle between the observation direction and the direction of surface periodicity. The Monte Carlo study of one-dimensional surfaces showed that U should be sensitive to variations in surface rms height or spectrum, and insensitive to variations in surface permittivity, and polar angle of observation. These results are promising for the use of U in satellite measurements.

The study of two-dimensional surface polarimetric brightness temperature showed that the properties of U observed in the one-dimensional case still hold in the two-dimensional deterministic surface case. U was found to indicate the azimuthal angle between the direction of observation and the directions of surface roughness and also to respond to the degree of surface anisotropy. This further strengthens the idea of using U for ocean wind remote sensing. The favorable comparison of the perfectly conducting surface model with measured ocean surface bistatic data indicates that the spectrum used for the ocean is a realistic one. The positive results of this project to data are expected to generate further interest in polarimetric techniques for passive remote sensing and to lead to the development of future polarimetric passive systems for Earth remote sensing.

1.3 Theoretical Models for Microwave and Millimeter Wave Integrated Circuits with Anisotropic Materials

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The scientific objective of this research is to develop computational models and techniques to deal with integrated circuits with anisotropic materials. The anisotropy could be naturally occurring or created artificially. The long-term goal is to evolve these models into inverse algorithms for speeding up the design process.

Part of this work involves macroscopic models of materials. To date, we have made stride in two areas: superconducting electronics and chiral media. In the case of chiral media, we studied the limitation of the Maxwell-Garnett mixing law and the weak-coupling approximation when they are applied to helix loaded dielectric materials. In the former case, the constitutive relation is obtained by modifying London's equations. Our formulation includes super-electron number density as a function of applied macroscopic current density, taking into consideration electron velocities distributions. This simplified model greatly facilitates the calculation of nonlinear resistance, inductance, and other quantities in superconduction electronic circuits.

We have also considered other composite structures that might be considered anisotropic at a larger scales. For example, the presence of multiple small apertures on a metal sheet will change the wave penetration properties. This structure is commonly seen in computer system enclosures. Our recent work took a semi-analytical approach by modeling the small apertures as interacting electric and magnetic dipoles. By using these dipoles in conjunction with finite-difference grids surrounding the interface, we save significant computation time without losing accuracy. A series of codes relating to apertures of various thickness and separation have been developed. This work should be of great interest to equipment manufacturers since it provides them a quick tool to examine EMI compliance with the FCC regulations.

1.4 Three-Dimensional Time-Domain Analysis of Microstrip and Monolithic Millimeter/Submillimeter Wave Integrated Circuits

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The scientific objective of this research is to understand the time-domain response in three-dimensional integrated hybrid microstrip circuits and for monolithic millimeter/submillimeter wave integrated circuits. These may include guiding structures, transitions and nonlinear terminations. The time-domain analysis serves as an effective tool leading towards engineering models for circuit design.

In certain connical structures, analytical techniques work well for modeling purposes. For example, recently a microwave network model of two parallel circular vias in a multilayer packaging was developed. This was achieved by replacing the via hole apertures with equivalent magnetic frill currents, the same used in cylidrical antenna theory. The circuit parameters are synthesized from the combination of even and odd mode equivalent circuits. Potential use of this model is for inclusion into CAD packages to reduce the complexity in circuit simulations.

With respect to numerical modeling, our attention has been on the recently developed "perfect matching layer" (PML) absorbing boundary condition. Parts of the study look into the PML as an artificial medium and investigate the "constitutive relation" of this medium, as well as the properties of propagating and nonpropagating plane waves at the PML interface. We observed that there is a systematic way to create a reflectionless interface, or PML "family". We also discovered that special constraints need to be placed on the matching layers in order to avoid numerical singularity when the core region of study is a multilayer medium. These discoveries allow us to move forward and comfortably apply the PML conditions to the analysis of dielectric waveguides.

1.5 Electromagnetic Modeling of Snow with Microstructures

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Project Staff

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On the ground, snow is a highly inhomogeneous medium consisting of mixture of ice particles, air, and liquid water. Seasonal snowpacks are also highly variable in time and space and are a very complex electromagnetic environment. To understand the influence of snow on the propagation of electromagnetic waves, we need to develop an appropriate method for studying the electromagnetic interaction with snow. The goal of this research is to develop a better understanding of (1) how the structure of inhomogeneities in snowcover will affect electromagnetic interaction, (2) how these effects can be parameterized, and (3) to quantify the effects of snow microstructure on millimeter wave backscattering signatures.

Our research strategy is based on the development of a more realistic microstructure model of snow and a rigorous technique for solving the electromagnetic scattering from snow terrain. In this work, we have used a sticky hard sphere (SHS) model to simulate the structure of grains of snow and the dense medium radiative transfer (DMRT) theory with the clustered particles as an electromagnetic scattering model of snow. The model which develops is then validated by comparing it with experimental snow data along with ground-truth measurements from past publications. The DMRT scattering model is further coupled to the snowpack physics model SNTHERM to interpret the diurnal variations of the millimeter wave radar returns from a series of experiments conducted by the University of Massachusetts at Amherst in March 1993.

The research performed during the period of June-December 1995 focused on the theoretical formulations and numerical simulations of electromagnetic wave propagation and scattering in media with adhesive scatterers, and their application to snowcover. Specifically, we have (1) investigated the electromagnetic wave interaction with snow microstructurer based on the dense medium radiative transfer theory (DMRT) in conjunction with a elustered sphere model for snow grains; (2) interpreted the polarimetric snow measurements performed by University of Massachusetts at Amherst in March 1993 and validated the proposed polarimetric radar clutter model of snow; and (3) developed a coupled model of DMRT and SNTHERM for predicting millimeter wave radar returns from snowcovers under various environmental condition.

1.6 Study of SAR Interferometry

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The SAR simulation model was recently expanded by adding a interferometric SAR (INSAR) capability. The major parts of INSAR algorithms include image interpolation and resampling, pixel registration, and phase unwrapping. INSAR provides a valuable means of generating topographical information from spaceborne radar images. Because our model simulates the physical mechanisms of radar scattering, it is a very useful tool to study the accuracy and sensitivity of different INSAR algorithms.

1.7 Inversion of Sea Ice Parameters

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The scientific goals of this research are (1) to investigate the dependence of active and passive microwave measurements on sea ice parameters and (2) to develop practical reconstruction methods for retrieving sea ice parameters by remote electromagnetic measurements. In this project, we have developed theoretical forward scattering models for sea ice and snowcover which include their morphological structures and physical properties. The scattering model has taken into account the combined volume and surface scattering effects for the accurate prediction of microwave signatures. Comparison between model results and experimental measurements with ground truth has been carried out to validate the models. The analysis has confirmed the volume scattering contribution due to the sea ice inhomogeneities, such as brine and air bubble inclusions, to the electromagnetic response of sea ice. The coupled volume and surface scattering mechanism is important in the understanding of sea ice physical properties and the reconstruction of sea ice parameters. An improved model of snowcover with clustered grain structure has been developed. It shows that the attenuation due to scattering is significantly enhanced in snow media by the aggregated particles.

A novel electromagnetic inverse scattering theory using time-series backscatter measurements has been developed to reconstruct the evolution of sea ice thickness. The inversion theory is based on a parameter estimation algorithm where the developed and validated theoretical model is used as the direct scattering model to compute electromagnetic signatures from sea ice. A robust optimization technique is then applied as the inverse algorithm to retrieve the sea ice parameters iteratively. This algorithm has been applied to microwave scattering data from laboratory-grown saline ice, the reconstructed thickness growth agrees closely with measured sea ice thickness. This inverse scattering theory has also been useful in retrieving more sea ice parameters, for example the size and distribution of brine pockets simultaneously from microwave measurements.

1.8 Study of Radio Interference on ILS Category III Operations

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Our emphasis is on the study of the effects of electromagnetic interference on the aircraft instrument landing system (ILS) Category IIIB (automatic (blind) landing operation). The objective is to gain a full understanding of radio interference on aircraft performance and to determine an acceptable level of interference for use in autoland certification. Previously, a computer package had been developed to assess the electromagnetic compatibility in ILS/MLS channel planning. It is proposed that this model is enhanced to include the industrial, scientific, and medical (ISM) sources in the interference study. The aircraft automatic flight control system (AFCS) model will be integrated with the receiver model to simulate the effect of interference on autoland performance. Ultimately, a standard on acceptable exposure time of FM broadcast interference will be developed from the study.

Our research work to date has resulted in a generic ILS receiver signal model and a generic autoland system model. The former includes propagation model and account for the least-denominator performance of the current generation of airborne ILS receivers, as well as an extrapolated receiver model conforming to future specification that is aimed at reducing radio interferences. The latter accounts for both ends of aircraft dynamics—twin-engine small jets and four-engine jumbo jets—and with control mechanisms with and without inertial smoothing. Monte Carlo simulations of different operation environments are applied to study the statistical behavior of aircraft dynamic responses, from which the risk probability of catastrophic failure can be derived.

1.9 MMW Model for Three-Dimensional Radar Scattering from Targets and Background

Sponsor

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Project Staff

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In this study, we extended the theoretical model of microwave remote sensing EMSARS to millimeter wave applications, producing graphical user interface (GUI) based three-dimensional scanning radar and SAR simulation programs. The baseline scenarios include the effects of environments, hard targets, atmospheric absorption and scattering, and ground reflection. With X-window/Motif graphical user interface, this program allows us to access the GIS feature map and the elevation map, and given sensor specification to create realistic radar images. The user not only can display elevation maps and the feature map, but also can identify and highlight particular terrain features in the map. Furthermore, the user can modify the feature map to investigate how radar images will change. The K-distribution clutter statistics model and simple terrain shadowing effect is included, as is the effect of rough scattering.

1.10 Electromagnetic Waves in Complex Media

Sponsor

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Project Staff

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This research is focused on theoretical studies of electromagnetic phenomena in complex media that will lead to applications in the modeling and analysis of realistic electronic systems. We concentrate our efforts on those characteristics that have major impacts on system behavior, in particular on electromagnetic interaction with detailed geometrical features and material properties.

Reduction of RF emission from electronic systems is becoming more critical these days as the lock rate of desktop computing systems increases. Most manufacturers still rely on empirical rules based on past experience for FCC-compliance in their design. The main reason for this is the absence of accurate design tools for the electromagnetic anaysis of realistic electronic systems which are often very complicated. Recently, numerical techniques based on the time domain form of Maxwell's equations have received increased attention due to the accuracy of the results obtained and the inherent efficiency of time domain techniques for solving wideband problems, such as EMI problem.

Our research focuses on developing analytical techniques that will reduce the scope and complexity of numerical models. The modeling of metalic enclosure is a practical problem aimed at capturing the effect of finite conductivity using the time domain numerical technique with miminal impact on the computation time. This was done by deriving a simple iterative procedure for including this dependence from DC to above microwave frequencies in numerical simulations. This inclusion is important in the analysis of RF emission from an electronic system with metal enclosure, since the behavior near resonant frequencies of the metal enclosure will be significantly impacted without proper modeling of this effect.

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