A newsletter from Communications and Space Sciences Laboratory

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PENNSTATE

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Director's Column

Incoherent Chatter!
This is the fourth issue of our newsletter and, as in prior newsletters, I'm pleased to report that CSSL students, staff, and faculty have been involved in a wide range of projects and events involving both research and education.

First of all, we're happy to welcome Drs. Christopher S. Ruff and Enrique Puliafito to CSSL. Chris joins us and the Electrical and Computer Engineering Department as an assistant professor. His interests center on microwave remote sensing of the Earth's surface and atmosphere. He is responsible for the science and engineering performance verification of the microwave radiometer on the TOPEX satellite. He will be collaborating with faculty and students in meteorological and middle atmosphere research efforts. Enrique, who is doing post-doctoral work with Charles Croskey, John Olivero, and Gerd Hartmann (Max Planck Institute für Aeronomie in Katlenburg-Lindau, Germany), is originally from Mendoza, Argentina. His activities here involve all aspects of radiometry from design through data reduction. He is helping in preparations for data reduction and interpretation for the flight of the MAS (Millimeter wave Atmospheric Sounder) on the space shuttle Atlantis in March.

There have been several sabbatical leaves this year. Dr. Lynn Carpenter has just returned from a sabbatical year at the Applied Physics Lab at Johns Hopkins University. His activities are described in the News section. Dr. Ray Luebbers is in Japan on sabbatical leave at the Laboratory of Electromagnetics at Tohoku University in Sendai. His work there involves various aspects of numerical electromagnetics and uses of the FDTD (Finite Difference Time Domain) codes in particular. Dr. C.C. Yang is also on leave, working on ultrafast phenomena in optical fibers and visiting both the University of Central Florida and National Taiwan University. Taking it easy in Hammond Building is Dr. John Mitchell, who is spending the year as acting Associate Dean for Undergraduate Studies in the College of Engineering.

In other news, Dr. Louis J. Lanzerotti of AT&T Bell Laboratories presented last year's Waynick Lecture, which is summarized in a later section. At this year's Waynick lecture, which will be held on April 3rd, CSSL/IRL graduate Peter Banks will speak on "Global atmospheric changes: Telltales and other interesting phenomena." Dr. Banks is the new dean of engineering at the University of Michigan.

The LADIMAS (LAtitudinal DIstribution of Middle Atmospheric Structure) campaign was a great success and is described in one of the feature articles. We congratulate three CSSL students, Joe Martone, Paul Haris, and Tim Stevens, for successfully voyaging from Germany to the Antarctic while operating a complex array of instruments. This scientific adventure was organized by Drs. Russell Philbrick and Ulf von Zahn.

Dr. J. K. Breakall has recently applied for a patent on his new Three-Dimensional Frequency Independent Phased-Array antenna. This exciting antenna is described in our second feature article. Finally, we are working to organize a follow-on to the AIDA-89 campaign organized by Colin Hines of Arecibo Observatory. This campaign, AIDA-LAMS (Arecibo Initiative in Dynamics of the Atmosphere – LAyers and MicroStructure) will hopefully occur in 1994 and involve instruments from several institutions including Penn State, the University of Illinois, and Cornell.

And congratulations are due! Dr. John J. Olivero received the Alan Berman Research Publication award from the Naval Research Laboratory, and as described below, Dr. Anthony J. Ferraro has been appointed to the Robert E. Kirby Endowed Chair.

John D. Mathews, director

The Unified Field Theory

Douglas H. Werner

Four kings govern their
respective domains
A different set of rules each
contains.

But understanding can only be
When the four are one in
harmony.

Waynick Lecture

Louis Lanzerotti is 1991 Waynick Lecturer

The 1991 Arthur H. Waynick Memorial Lecture was presented in the Walker Building Auditorium on May 11, 1991, by Dr. Louis J. Lanzerotti, who spoke on "Impacts of Solar-Terrestrial Activity on Technological Systems."

Dr. Lanzerotti is a Distinguished Member of the Technical Staff, AT&T Bell Laboratories, and is also an adjunct professor of electrical engineering at the University of Florida. He has long been active in space-related research, particularly concerning the effects of solar disturbances on communications systems and power distribution systems. He has served as chairman of the NASA Space and Earth Science Advisory Committee and as chairman of the Space Studies Board of the National Research Council. Among his many honors and awards has been election to the National Academy of Engineering and to Fellow grade in the American Physical Society and in the American Geophysical Union.

Dr. Lanzerotti began his talk with a brief overview of the direct effects of high-energy solar radiation on the Earth's atmosphere. He pointed out that the same radiation that under normal conditions produces the ionization that supports worldwide radio communication can, under disturbed conditions, disrupt these same communication links.

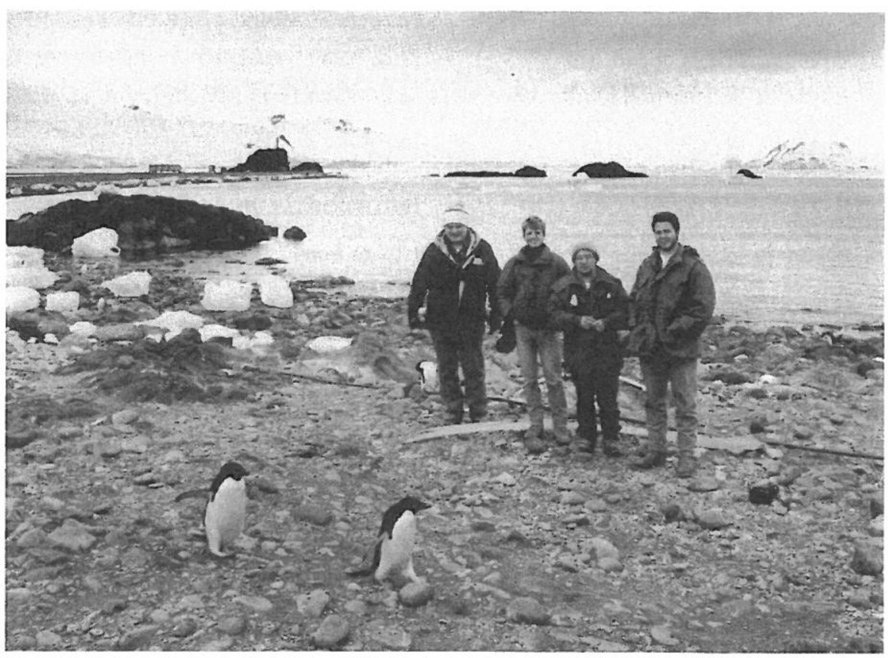
The central topic of the talk, however, was concerned with more indirect effects, where induced currents occur in extended systems of electrical conductors such as power grids, railroads, oil pipelines, etc. These effects are most intense at higher latitudes in the auroral and sub-auroral zones, but they can also be seriously destructive at middle latitudes. As particular examples of such phenomena, Dr. Lanzerotti cites historical records of breakdowns in wire telegraph services, dating from their inception in the mid-nineteenth century, and the severe damage and blackouts experienced by electric power utilities in 1989 and 1990, both in Europe and North America. These latter events are attributed to major solar outbursts in the present maximum of the 11-year sunspot cycle.

The principal conclusion drawn by Dr. Lanzerotti was that the design of many of our present technological systems does not provide adequately for worst-case scenarios in the impact of solar-terrestrial effects. With improved understanding of these phenomena, it should be possible to design systems that will withstand the stresses caused by these infrequent but inevitable events.

Features

LADIMAS takes CSSL to the Antarctic

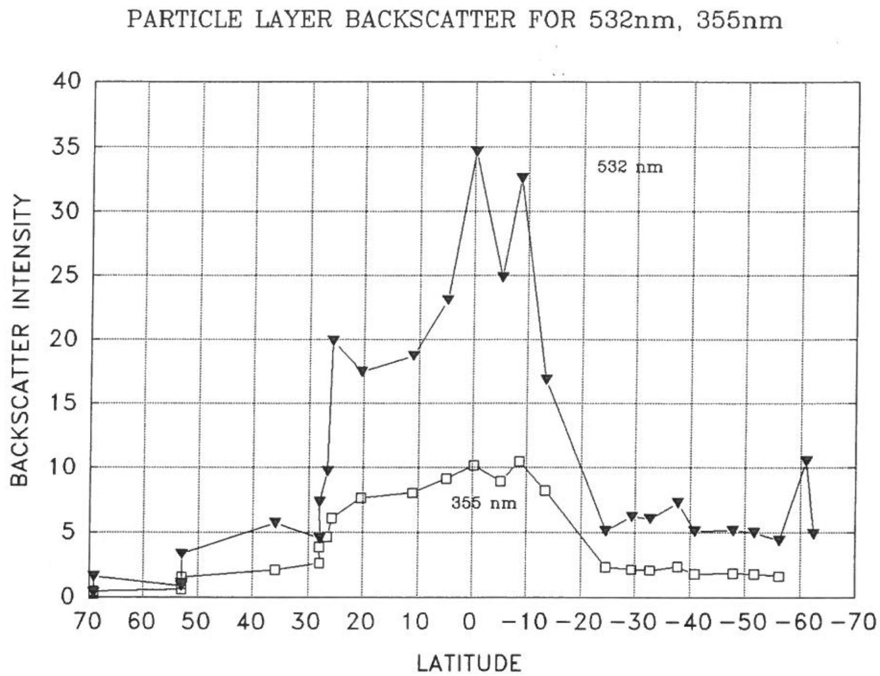
Three CSSL experiments traveled from Northern Europe to Antarctica on board the German research vessel *Polarstern*, taking part in a scientific expedition lasting from October 8, 1991, to January 2, 1992. CSSL participation grew out of a collaboration between CSSL scientists and Dr. Ulf von Zahn (an associate member of CSSL) of the University of Bonn, who in 1990 spent six months at CSSL as a visiting professor. Penn



"Dr. Philbrick, I presume?" Friendly Antarctic natives greet Russ Philbrick, Paul Haris, Joe Martone, and Tim Stevens.

State University and the University of Bonn were invited to participate in the 1991 voyage of the Polarstern by the Alfred Wenger Institute of Germany, who operate the research vessel. The co-principal investigators of the LADIMAS campaign were Dr. von Zahn for Germany and Dr. C. R. Philbrick for the United States.

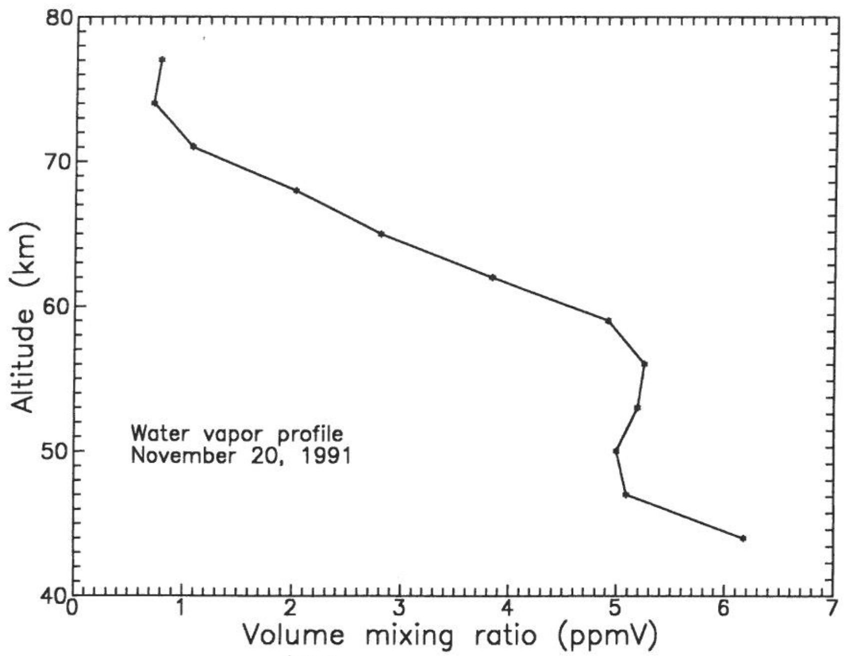
The LADIMAS campaign (LAtitudinal DIstribution of Middle Atmospheric Structure) used remote sensing techniques to determine the dynamical processes and layering structures of the chemical constituents of the middle atmosphere. Information on important dynamical processes, such as gravity waves, tidal components,and the formation of the layers of meteoric species, was obtained with three lidars, a digisonde, a microwave radiometer, and several spectrometers. Several of the parameters studied (e.g., the altitude profiles of density and temperature of the middle atmosphere or density of meteoric species) have never been measured before over such a wide range of latitudes. Data collected, as a function of latitude from 70°N to 65°S, includes height profiles of atmospheric density and temperature (1 to 80 km), meteoric minor species (iron and sodium) profiles (80 to 110 km), water vapor from a microwave radiometer (40 to 80 km), digital ionosonde profiles of electron/ion density (85 to 150 km), mesospheric ozone variation from an O_2 (1D) spectrometer (90 to 95 km layer),



The Penn State lidar on the *Polarstern* measured the particle scattering created in the stratosphere between 20 and 25 km by the Pinatubo volcano eruption. The transit of the ship between 70°N and 65°S during November and December 1991 provided measurements of the increased ratio of the particle scatter to the normal molecular scatter intensities at wavelengths in the visible (532 nm) and ultraviolet (355 nm). The volcano erupted in the Philippines on 15 June 1991 and has produced the largest optical scattering feature of this century. The lidar has obtained a high resolution map of the particle scattering that will be valuable in determining its effects as a test of global warming/cooling models that are currently being developed.

Instruments of the LADIMAS Campaign

Fe(iron) Resonance Lidar 80-110 km dynamics	University of Bonn Dr. Ulfvon Zahn
Na(sodium) Resonance Lidar 80-110 km dynamics and T	University of Bonn Dr. Ulf von Zahn
LAMP - Lidar for molecular, particle, and Raman scatter measurements 200 m to 80 km T, D, H_2O and particle scatter	Penn State University (CSSL and ARL) Dr. C. R. Philbrick
Microwave Radiometer 40 to 80 km H_20 emission at 22 GHz	Penn State University (CSSL) Dr. C. L. Croskey and Dr. J. J. Olivero
Digital Ionosonde electron/ion density	Penn State Univ. (CSSL) and University of Lowell Dr. John Mathews (CSSL) Dr. C. R. Philbrick (CSSL) Dr. Bodo Reinisch (U. of Lowell)
OH IR Spectrometer 82-92 km OH intensity and layer T	Wuppertal University Dr. D. Offerman
O_2 NIR spectrometer 88-95 km layer T	Univ. of Saskatchewan Dr. T. Llewellyn



A profile of the water vapor mixing ratio in the 40-to-80 km altitude region measured by the Penn State microwave radiometer on the *Polarstern*. The latitudinal survey of water vapor performed during the voyage will contribute to our understanding of the chemistry and dynamics of these regions. Long-term global changes in the atmosphere, such as the Antarctic ozone hole, will be monitored by many instruments, including the Penn State microwave radiometer, as part of NASA's Network for the Detection of Stratospheric Change.

profiles of aerosols/cloud particles (surface to 40 km), and temperature measurements from 85 km with an OH spectrometer. In addition, several rawinsonde meteorological balloons were released each day.

One of the Penn State instruments that participated in LADIMAS was a Nd:YAG-based lidar system developed by faculty and graduate students of CSSL and Penn State's Applied Research Laboratory's LAMP initiative (Laser Atmospheric Measurements Program). Objectives of this experiment were density and temperature profiles from molecular scatter of the gases of the middle atmosphere (45-80 km), density and temperature profiles measured from the ground upward using two-color lidar and Raman detection, molecular nitrogen profiles up to 30 km, and water vapor profiles up to 5 km altitude. Lidar (LIght Detection And Ranging) is a radar that uses light waves instead of radio waves. As with radar, lidar measures the distance to an object by the time it takes for energy (visible light) to reach and return from it. This lidar uses a high-powered laser for remote sensing of atmospheric properties. The lidar collects backscattering signals from molecules, dust, and aerosols. Analysis of the signals returned yields the atmosphere's density and temperature profiles and its concentrations of water vapor, meteoric debris, and aerosols. A powerful pulsed laser permits long-range detection of the scattering target. The LAMP instrument is an advanced laser remote measurement sensor that measures the molecular and Raman scatter signals at several wavelengths to determine the profile distributions of density, temperature, particle scatters, and water vapor. The transmitter is a high-power Nd:YAG laser with an output of 1.5 J/pulse at 20 Hz. The fundamental wavelength is doubled to obtain 600 mJ pulses at 532 nm and mixed to obtain 250 mJ pulses at 355 nm. The transmitter, receiver, detector, and data system combination, which has been set up in a shipping container/laboratory, can obtain data from near the surface to altitudes of 80 km. The measurements of the backscatter radiation are made at the fundamental wavelengths of 532 and 355 nm with several different detectors in order to cover the appropriate spectral region over a wide dynamic range. A dynamic range of nine decades is needed to cover altitudes from 1 to 80 km. CSSL graduate students Paul Haris and Tim Stevens operated the LIDAR on the voyage. Penn State Principal Investigator Dr. Russell Philbrick joined the voyage in Argentina for the last leg of the journey to Antarctica. Dr. Daniel Lysak of ARL participated in lidar operations in northern Norway and on the Polarstern's voyage from Norway to Bremerhaven, Germany. Donald Upshaw, research associate in ARL, was responsible for program management and logistics, working with personnel of the Alfred Wenger Institute of Germany, operator of the *Polarstern*. He traveled to Norway and Germany to oversee the loading of the instrument container (8 ft. by 20 ft. by 8-1/2 ft. and weighing about 10 tons) on the ship. Thomas Collins, head of Penn State's Electronic Design Services, participated in equipment installation in Bremerhaven, and worked with the students to obtain data on the *Polarstern* from Germany to Argentina.

Another Penn State experiment aboard the *Polarstern* was a microwave radiometer that measured water vapor in the stratosphere and mesosphere (40 to 85 km altitude). The radiometer was designed and constructed by graduate student Joseph Martone, who also operated it continuously during the voyage from Bremerhaven, Germany, to the Antarctic. Although water vapor plays a major role in the photochemistry of the stratosphere and mesosphere, its concentration in these regions is not well known. Above 70 km photo-dissociation of water vapor by solar radiation is a major sink of the water vapor that diffuses up from below. The atomic hydrogen that is produced from the dissociation of water vapor escapes into the exosphere and is a major loss term in the hydrogen budget of the earth. Water vapor can also be used as a tracer of atmospheric motions and dynamics because of its long chemical lifetime. The water vapor products (HO_x) have a strong influence on ozone in the upper stratosphere and mesosphere. The microwave radiometer remotely senses the amount of water vapor in the 40 to 80 km altitude regions of the atmosphere by observing the thermal emission of the water vapor in that region. This thermally excited signal at 22 GHz can be observed if the background noise of the receiver is low enough. In this region of the microwave spectrum, the Planck radiation function can be simplified such that the received power from the atmosphere can be directly related to an apparent brightness temperature. This apparent brightness temperature is related to the physical temperature of the water molecule and the amount of water vapor. Below about 80 km, the 22.235 GHz line of water vapor is almost entirely pressure broadened. It is this dependence on pressure that makes retrieval of the water vapor profile possible. The radiometer has a full bandwidth of 500 MHz centered on the 22.235 GHz line and uses a transistor preamplifier that is cooled to 20 Kelvins to obtain the required low-noise background. Additional parts of the equipment perform spectral analysis to determine the altitude distribution of the water vapor. These water vapor measurements are the first to be made over such a wide range of geographic latitudes. Dr. Charles Croskey and Dr. John Olivero of CSSL were co-investigators of the radiometer experiment.

A third experiment involving Penn State was a digisonde that measured electron density from 90 to 150 km to look for sporadic E layers, which may yield information regarding the sodium and iron lidar profile measurements. The Digisonde 256, from the University of Lowell, in its normal configuration can perform vertical as well as oblique sounding of the ionosphere. In order to reduce the interference with the ship's radios, it had to be extensively modified until the level of interference was acceptable to the ship's radiomen, with the result that the transmitter power was reduced from an input power of 10 kW to 50 W. Even with this greatly reduced power, during the first day at sea the system was able to receive echoes from the E and F regions in the vertical mode. The system recorded sporadic E on twelve different occasions. Whenever the Digisonde and Fe-lidar were operating simultaneously, when the Digisonde detected sporadic E, a sporadic iron layer was observed by the Fe-lidar. Dr. John Mathews and Dr. Russell Philbrick of CSSL and Dr. Bodo Reinisch of the University of Lowell were co-investigators on this experiment.

The LADIMAS campaign has produced a unique body of data that will be analyzed over the next couple years. The results will impact research areas varying from global warming and ozone depletion to meteoric debris.

Support for the development and carrying out of the lidar experiment is from Applied Research Laboratory Research Initiative, The Environmental Systems Program Office of the Navy, and National Science Foundation's Science Division Program on Coupling Energetics and Dynamics of Atmospheric Regions (CEDAR). Support for the radiometer experiment is from NASA. Dr. von Zahn's work was supported by Deutsche Forschungsgemeinschaft, Bonn, Germany.

Breakall develops new antenna design

Dr. James K. Breakall recently invented a new antenna concept that potentially could have a great impact in phased array technology. He has formally submitted a patent disclosure, and a patent application has been written and presented to the U.S. Patent Office by the Intellectual Property Office of Penn State. We would like to present the following reprint describing this invention, which was submitted to the 1992 Symposium of the Applied Computational Electromagnetics Society, March 1992.

An Introduction to the Three-Dimensional Frequency-Independent Phased-Array (3D-FIPA)

A new and innovative antenna array, the Three-Dimensional Frequency-Independent Phased-Array (3D-FIPA), was developed by Penn State and is described in detail in this paper. This antenna has been entered into the patent process after extensive physical and computer modeling analysis. The 3D-FIPA can be designed to provide low grating lobes, low sidelobe levels, nearly constant gain, beamwidth, and impedance with a low Voltage Standing Wave Ratio over extremely large bandwidths. The full array maximizes use of physical volume required and can be built for HF through the microwave regions. The 3D-FIPA applies the log-periodic principle in a novel way to form multi-layer dipole arrays that maintain all electrical spacings and heights over a user-specified frequency range.

I. Introduction

Phased-array antennas have traditionally been composed of a group of similar, individual element antennas or radiators oriented along a line (a linear array) or in a two-dimensional plane (a planar array). The configurations have provided the ability to form a single, directed, pencil-beam, fan beam, or even multiple beams. The formation and characteristics of the beam or beams were controlled entirely by amplitude and phase excitations of individual element radiators in the antennas. The main beam was scanned in space by changing the phasing, and excitation of individual radiating elements. The shape of the beam (its width and sidelobes) was controlled by amplitude, phasing and spacing of the radiating elements. Scanning of the beam was accomplished completely electronically.

Phased arrays have been used in many applications including electronically steered radar, shortwave broadcasting, curtain arrays, over-the-horizon radars, ionospheric modification antennas, satellite communications, broadcasting antennas, AM broadcast service antennas, etc.

At Penn State, recent analysis of the antenna needs for a world-class ionospheric research instrument to be constructed in Alaska has resulted in the development of a new and innovative antenna called the Three-Dimensional Frequency-Independent Phased-Array (3D-FIPA). This antenna has been proposed for the High Frequency Active Auroral Research Program (HAARP) of the Navy/Air Force for the unique design concept of a world-class high-power instrument for modification and research of the auroral ionosphere. Study has shown that there are major difficulties with all current ionospheric modification arrays and phased arrays in general when desirable characteristics are to be achieved over very wide bandwidths. Traditional phased arrays, when operated over a wide bandwidth, have the inherent drawbacks of limited frequency range, disastrous grating lobes, inability to control sidelobes, limited scan elevation and azimuth angles, inability to add future modifications, and limited bandwidth for very fast slewing of the beam. Rapid beam steering and frequency agility, which require large bandwidths, are characteristics which can be satisfied very easily with this new design.

The design presented in this paper incorporates an original phased-array antenna with the following frequency-independent characteristics: low grating lobes, low sidelobe levels, nearly constant gain, beamwidth, and impedance, and low Voltage Standing Wave Ratio (VSWR) over any desired user-chosen frequency bandwidth. This antenna, for which the patent process has begun, is believed to be the first solution ever proposed that will achieve all of the above characteristics. It applies the log-periodic principle in a novel way to form multi-layer dipole arrays that maintain all electrical spacings and heights over a user-specified frequency range.

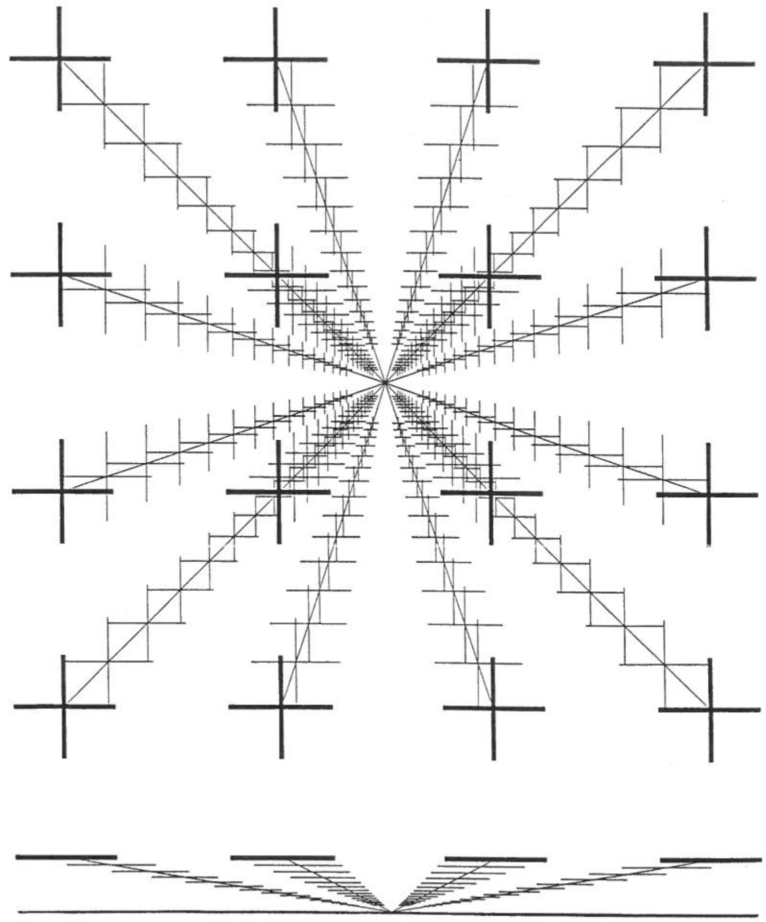


Figure 1. 4-by-4 3D-FIPA (top and side views) shown excited at the lowest frequency.

II. Background
A detailed examination of the most important and unique features that can be obtained only with the 3D-FIPA antenna follows:

Suppression of grating lobes is extremely important to insure a clean main beam pattern and prevent power from being wasted in unwanted directions. Any conventional array cannot achieve low grating lobes over a wide frequency range because the element spacings expressed in wavelengths increase with frequency, creating interferometer-like grating lobes. The only solution is to construct many narrowband phased arrays so that the spacing changes by only a small percentage with frequency. The range is so limited, however, that many arrays have to be built, and very complex switching systems must be employed. The 3D-FIPA antenna solves all of these problems by preserving all spacings and heights above ground (expressed in wavelengths) for active resonant elements as the frequency is varied. Every geometrical parameter of the antenna is therefore constant with frequency in a log-periodic sense.

Constant gain and beamwidth as a function of frequency is a very desirable characteristic of the 3D-FIPA antenna. Any array with constant physical distance between the elements, such as a conventional phased array, has gain-versus-angle characteristics that change greatly with frequency, even if the individual elements are inherently wideband. The 3D-FIPA antenna is designed to keep the electrical area constant with frequency. The decrease with frequency of the physical area covered by the active radiating elements causes this constant electrical performance. The gain and beamwidth remain extremely close to constant in a manner very similar to that of a single log-periodic element. Voltage Standing Wave Ratio also is low throughout the complete frequency range because of the log-periodic concept utilized in the design.

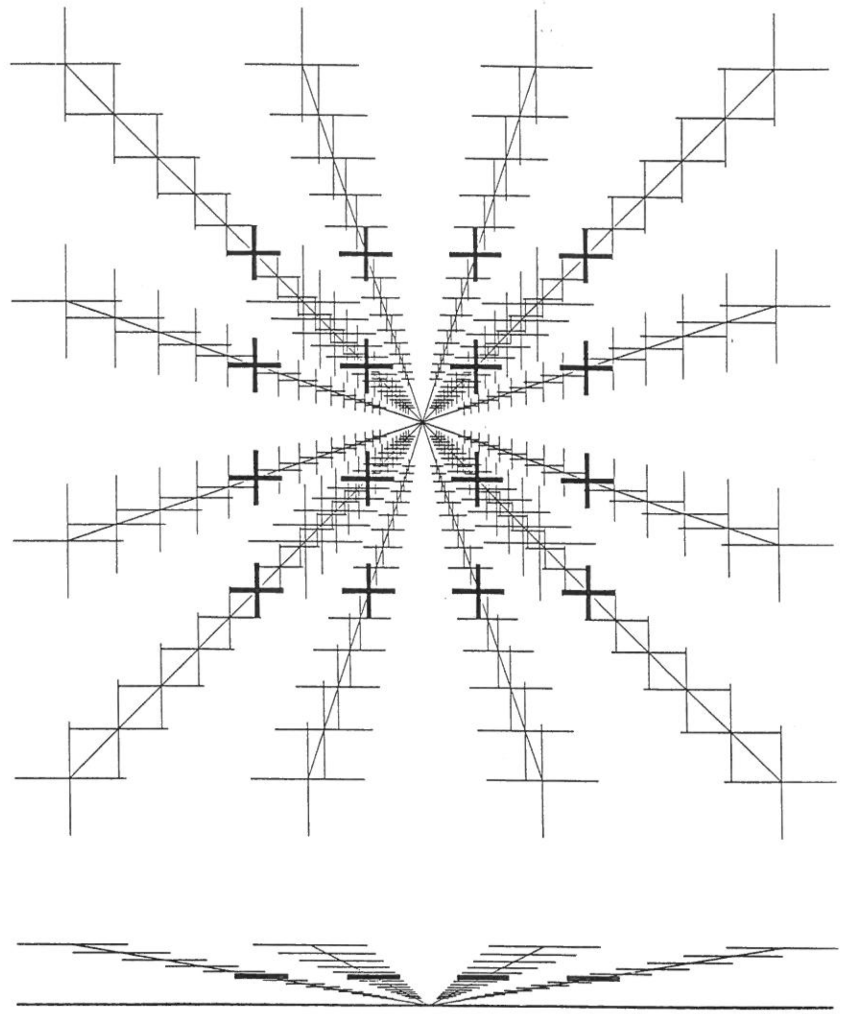


Figure 2. 4-by-4 3D-FIPA (top and side views) shown excited at a middle frequency.

The 3D-FIPA has a coincident location where all feedpoints intersect at a common location, making excitation and phasing simpler than in a distributive system. Finally, the usage of physical volume and area is conserved by the judicious arrangement of nesting each subarray inside of other subarrays, all at different heights and specified non-intersecting locations.

Extensive code and experimental validation has established the superior performance of the 3D-FIPA. Measurements have been successful on several reduced-scale models of different versions of the 3D-FIPA. Gain, impedance, VSWR, beam slewing, interaction with other wires and feedlines, and optimization of geometrical considerations have all been parametrically examined.

III. Description of 3D-FIPA Antenna
Positioning of the various log-periodic antenna structures in the 3D-FIPA is such that each wire's height above a ground plane is some constant in wavelengths (i.e., .25λ) at each wire's resonant frequency. At the prescribed height in wavelengths above the ground plane, each wire's center is also at a constant spacing in wavelengths (i.e., .60λ) from adjacent like wire centers. Scaling of the antenna elements in a log-periodic sense causes physical wire lengths, heights, and inter-wire spacings to get

progressively smaller as one moves towards the feed end of the element. The scaling factor is the same tau factor as used in classical log-periodic antenna design.

Figures 1 and 2 show both overhead and side views of a 4-by-4 circularly polarized version of the 3D-FIPA. The dark highlighted antenna wires depict the planar nature of the array with excitation at a single frequency. Figure 1 shows the array excited at the lowest operating frequency. Figure 2 shows the same array excited at a middle frequency. At the highest frequencies the array element nearest the center and closest to the ground are excited. These figures depict the constant above-ground heights and constant spacings of the antenna wire elements, a point that was discussed earlier. A total of 32 feed points would provide beam slewing in all directions with switchable polarization.

IV. Conclusions

The 3D-FIPA concept can be thought of as having many separate N-by-N vertically stacked dipole planar subarrays of fixed spacings in wavelengths. Subarray dipole elements expand from the center of the array to maintain proper electrical spacings. The highest frequency planar subarray is at the lowest physical height. As frequency is lowered, the physical plane occupied by the planar subarray successively rises above the ground plane. The heights and horizontal spacings in wavelengths for the dipoles in the subarrays are constant with frequency.

To summarize, all presently known phased arrays have severe problems when large frequency ranges of operation are to be achieved. The 3D-FIPA antenna described here solves current phased-array design problems.

Abstracts

92-S/1 A thin dipole antenna demonstration of the antenna modeling capabilities of the finite difference time domain technique

K. S. Kunz, R. J. Luebbers, and F. Hunsberger (all of CSSL)

The Finite Difference Time Domain (FDTD) technique has been successfully applied for modeling the electromagnetic scattering from and coupling into a variety of objects. In this communication we use FDTD to compute the input impedance of a thin dipole antenna. The short circuit current and open circuit voltage at the antenna terminals are computed over a wide bandwidth using pulsed plane wave excitation, then Fourier transformed to the frequency domain and divided to obtain the complex input impedance over a wide bandwidth using one FDTD computation. These results are compared with thin wire antenna results using the Method of Moments and good agreement is obtained except at very low frequencies, where the FDTD results obtained using this approach lose accuracy due to the imperfect outer absorbing boundary.

Applied Computational Electromagnetics Society Journal 5:2-7, 1990.

92-S/2 Extension of the finite-difference time-domain method to gyrotropic media

F. P. Hunsberger, Jr. (CSSL)

The Finite-Difference Time-Domain (FDTD) method is a computationally intensive technique for solving electromagnetic propagation and scattering problems. Because FDTD demands large amounts of computer storage and long execution times, it has gained wider acceptance with the advances made in computer technology over the last fifteen years. FDTD simulations which at one time required supercomputers are now being routinely performed on desktop computers.

Like other computational electromagnetic techniques, FDTD is not without limitations. The focus of this thesis is to extend the capability of FDTD to model materials which cannot be modelled using current FDTD formulations.

Although the method inherently produces transient data, many researchers continue to use FDTD solely for sinusoidal steady-state analysis. One reason for this is that materials with frequency-dependent electrical parameters cannot be modelled using traditional algorithms. A new FDTD formulation is presented here which efficiently incorporates the transient properties of these dispersive materials. As demonstrations of this new method, polar dielectrics and dispersive conducting materials are examined.

Along with this dispersive capability, FDTD is extended to the more advanced class of gyrotropic materials. Due to the anisotropic and sometimes dispersive properties of these materials, wavenumbers for propagating waves will be direction-dependent. As a result, Faraday rotation is possible, where linearly polarized waves undergo rotations as the wave propagates through the medium. Three specific examples of gyrotropic materials are examined here and, because of the different internal mechanisms producing the gyrotropy, three different FDTD formulations are derived. The results are new transient methods of analyzing magnetoactive plasmas, magnetized ferrites, and naturally optically active, or chiral, materials.

Ph.D. Thesis, May 1991, R. J. Luebbers, Thesis Adviser

92-S/3 A frequency-dependent finite-difference time-domain formulation for transient propagation in plasma

R. J. Luebbers, F. Hunsberger, and K. S. Kunz (all of CSSL)

Computation of transient electromagnetic propagation through plasma has been a difficult problem. Frequency domain solutions are