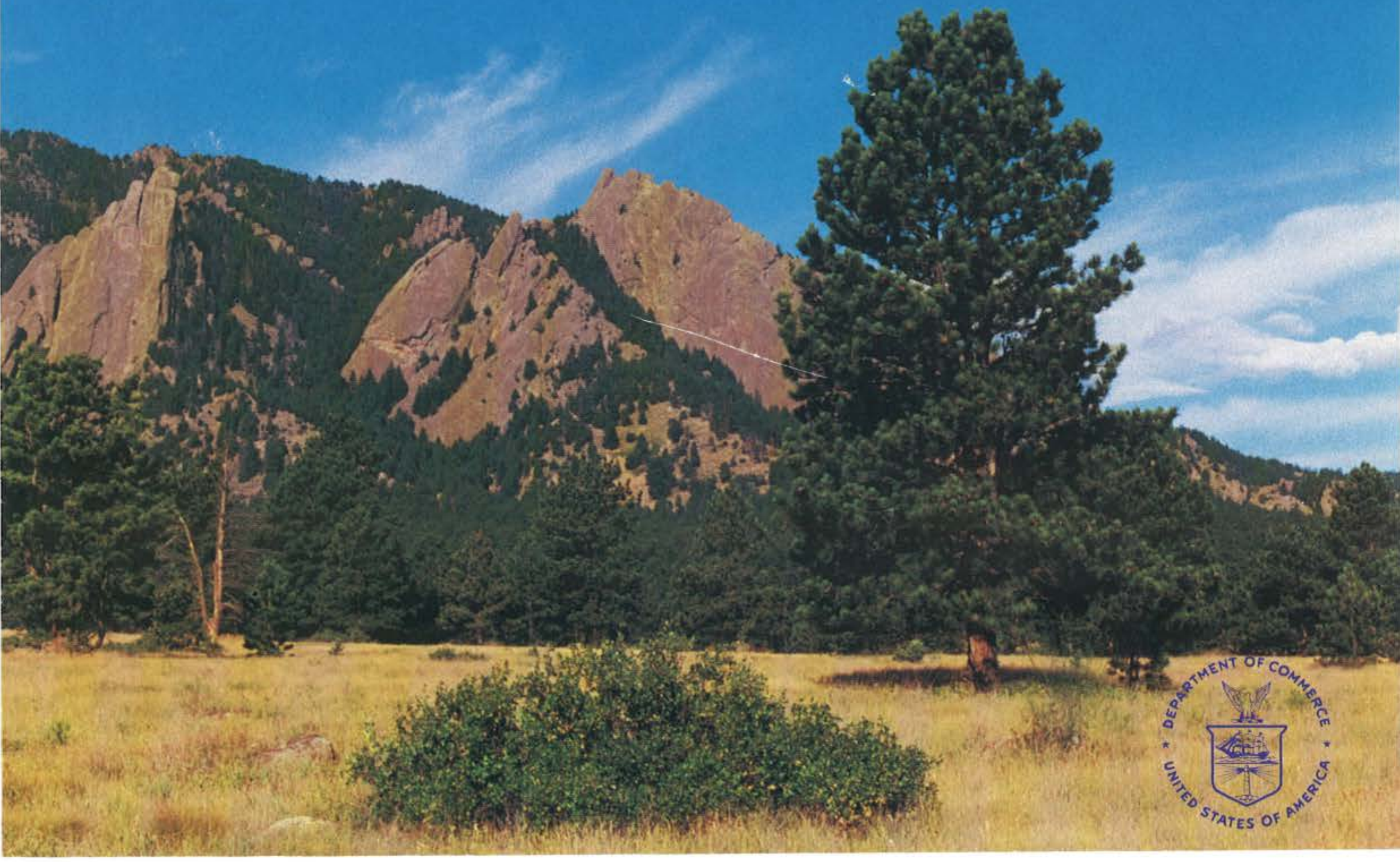
INSTITUTE FOR TELECOMMUNICATION SCIENCES

OF THE

NATIONAL TELECOMMUNICATIONS
AND
INFORMATION ADMINISTRATION

TECHNICAL PROGRESS REPORT 1994

FOR THE PERIOD
OCTOBER 1, 1993 THROUGH SEPTEMBER 30, 1994



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U.S. DEPARTMENT OF COMMERCE
RONALD H . BROWN, SECRETARY
LARRY IRVING, ASSISTANT SECRETARY
FOR COMMUNICATIONS AND INFORMATION

The 1994 Technical Progress Report for ITS was produced at the Institute and edited by Natalie Sexton, Technical Publications Editor, and Dave Sutherland under the overall guidance of Val M. O'Day, Executive Officer. Glenn Hanson, Frank Sanders, and Brad Ramsey provided advice and assistance on color photography. Help with production software and layout was provided by Judy Henderson. Guidance and direction on the report's contents was provided by the ITS Deputy Directors, Neal B. Seitz and Kenneth C. Allen.

On the cover: Ponderosa pine with mountain mahogany, in the foreground, and the Flatirons in the background encompass the view on Enchanted Mesa just west of the Department of Commerce Boulder Laboratories.

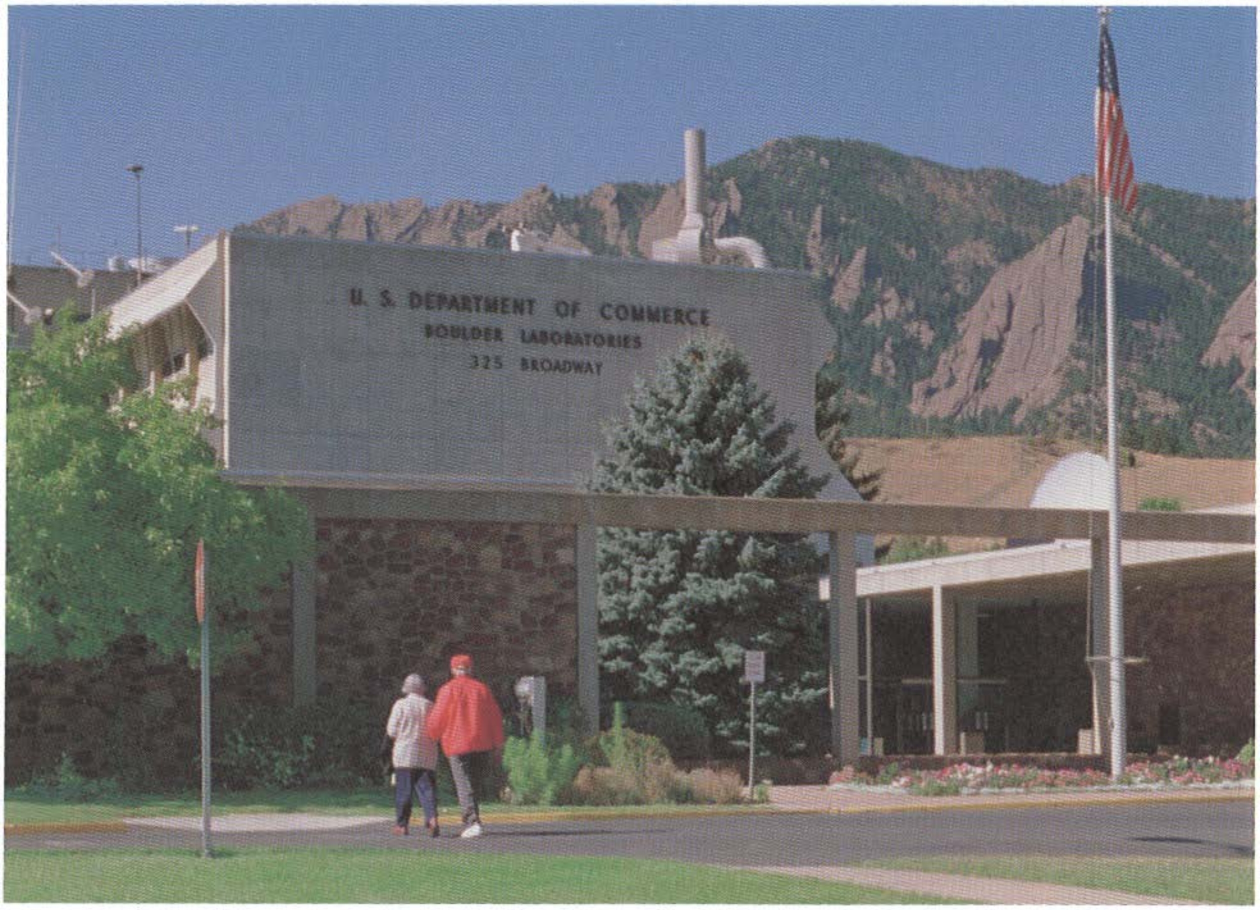
CONTENTS

THE ITS MISSION

As the chief research and engineering arm of the National Telecommunications and Information Administration (NTIA), the Institute for Telecommunication Sciences (ITS) supports NTIA telecommunications objectives such as promoting advanced telecommunications and information infrastructure development in the U.S., enhancing domestic competitiveness, improving foreign trade opportunities for U.S. telecommunications firms, and facilitating more efficient and effective use of the radio frequency spectrum.

ITS also serves as a principal Federal resource for assistance in solving telecommunication problems of other Federal agencies, state and local governments, private corporations and associations, and international organizations.

Cooperative research agreements based upon the Federal Technology Transfer Act of 1986 are the principal means of aiding the private sector. This Act provides the legal basis for and encourages shared use of government facilities and resources with the private sector in advanced telecommunications technologies to aid in attaining commercialization of new products and services.



ITS Is Located in the Department of Commerce Laboratories, Boulder, Colorado.
Photograph by D. Sutherland.

Forest Service Fire Lookout Tower with Land Mobile Radio Antenna Mounted Near the Cab. See Advanced Systems Planning, Page 42. *Photograph by W.R. Rust.*

OVERVIEW

The Institute for Telecommunication Sciences (ITS), located in Boulder, Colorado, is the chief research and engineering arm of the National Telecommunications and Information Administration (NTIA) of the U.S. Department of Commerce. ITS employs approximately 110 permanent program staff. These employees bring substantial engineering and scientific backgrounds, skills, and experience to our technical programs. The majority of our employees (62%), are electronics engineers, while 5% are mathematicians, 5% are physicists, 2% are computer scientists, and 2% are computer programmers. ITS' support during the 1994 fiscal year consisted of $4.3 million of direct funding from the Department of Commerce and approximately $8.6 million for work sponsored by other Federal Government agencies and U.S. industry.

HISTORY

ITS had its beginnings in the 1940's as the Interservice Radio Propagation Laboratory, which later became the Central Radio Propagation Laboratory (CRPL) of the National Bureau of Standards of the Department of Commerce. In 1965, CRPL became part of the Environmental Science Services Administration and was renamed the Institute for Telecommunication Sciences and Aeronomy (ITSA). In 1967, the telecommunications function of ITSA was transferred into the newly formed Office of Telecommunications (OT). Finally, under the President's Reorganization Act #1 of 1977, OT and the Office of Telecommunications Policy merged to form NTIA. Since that time, ITS has performed telecommunications research and provided technical engineering support to NTIA and to other Federal agencies on a reimbursable basis. Recently, ITS has also pursued cooperative research with U.S. industry under the provisions of the Federal Technology Transfer Act of 1986.

ACTIVITIES

The Institute performs telecommunications research, planning, and engineering in the following areas:

- **Spectrum Planning and Assessment**. Technical analyses of spectrum use in selected frequency bands and preparation of U.S. technical positions for international spectrum allocation conferences.
- **Telecommunications Standards Development**. Contributions to and development of Federal, national, and international telecommunications standards.
- **Telecommunication System Planning.** Relating needs of users to the capabilities of a planned network.
- **Telecommunication System Performance Assessment**. Forecasting the performance of individual communication elements in a system and testing and measuring systems in a laboratory or operational environment.
- **Applied Research**. Modeling the way radio waves travel from point to point in various frequency bands and evaluating the way information is carried by radio signals, including modulation and coding.

BENEFITS

The Institute's work significantly benefits both the public and private sectors in several areas:

- **Spectrum Utilization**. Optimization of Federal spectrum allocation methods, identification of unused frequencies and potential interference through field measurements, and promotion of technology advances to aid in efficient use of the spectrum.
- **Telecommunications Negotiations**. Expert technical leadership at international conferences and development of negotiation support tools such as interference prediction programs.
- **International Trade**. Promulgation of nonrestrictive international telecommunications standards to remove technical barriers to U.S. export of telecommunications equipment and services.
- **Domestic Competition**. Development of user-oriented, technology-independent methods of specifying and measuring telecommunications

performance to give users a practical way of comparing competing equipment and services.

- **National Defense**. Improvement of network operation and management, enhancement of survivability, expansion of network interconnections and interoperation, and improvement of restoration of emergency communications to contribute to the strength and cost effectiveness of the U.S. Armed Forces.

- **Technology Transfer**. Direct transfer of research results and measurements to U.S. industry and local governments to support international and national competitiveness, to hasten the advent of new technology to users, and to expand the capabilities of the national and local telecommunications infrastructure.

OUTPUTS

Major outputs of the Institute's research and engineering activities include:

- **Engineering Tools and Analyses**. Predictions of transmission media conditions and equipment performance; test design and data analysis computer programs; laboratory and field tests of experimental and operational equipment, systems, or networks.

- **Standards, Guidelines, and Procedures**. Contributions to and development of national and international standards in such areas as network interconnection and interoperation, performance evaluation, and information protection.

- **Research Results**. Models for electromagnetic wave propagation, noise, and interference characterization.

- **Expert Services**. Training courses and workshops to communicate technology advances and applications to industry and Government users.

ORGANIZATION

ITS is organized into two program divisions: Spectrum Research and Analysis, and Systems and Networks Research and Analysis. Each of the program divisions is organized into functionally oriented groups as indicated in the Figure.

Work performed by the Spectrum Division involves analyses directed toward understanding radio wave behavior at various frequencies and determining methods to enhance spectrum use. The Systems and Networks Division focuses on assessing and improving the performance of telecommunication networks within the Government and the private sector, developing domestic and international telecommunications standards for networks, and evaluating new technologies for future needs.

The ITS Executive Office, located within the director's office, handles administrative matters. The Executive Office also handles the Institute's budget and program planning functions and interacts with various administrative offices within other parts of the Department of Commerce to achieve its payroll, procurement, personnel, facilities management, civil affairs, and publications requirements.

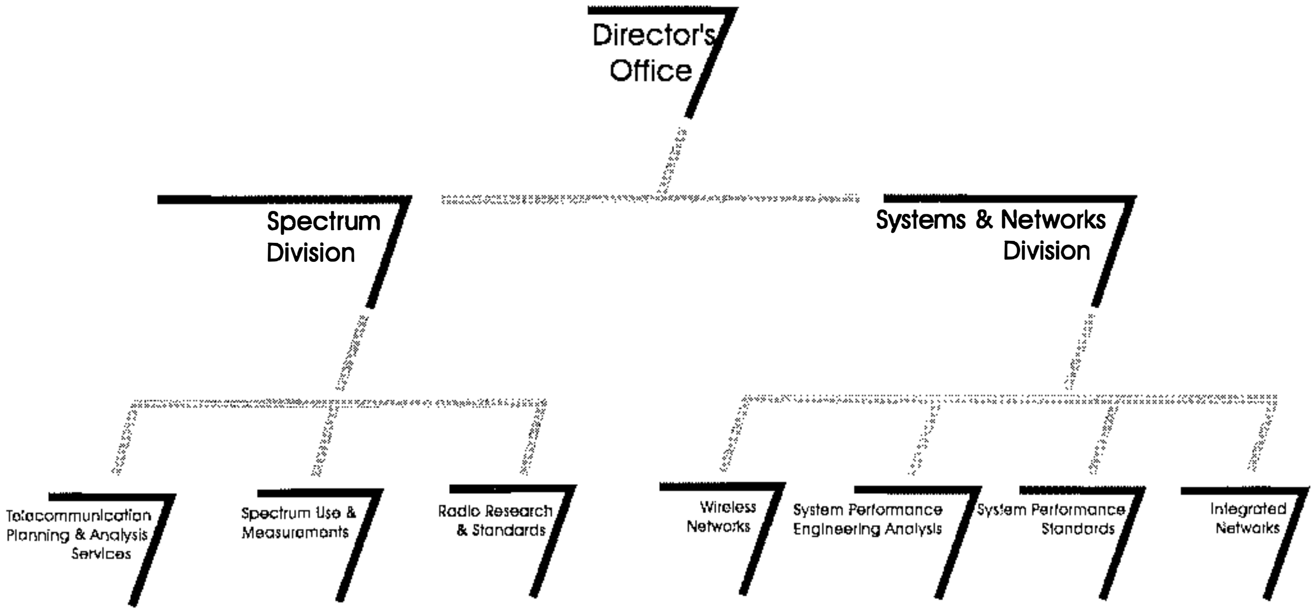
SPONSORS

The activities of ITS are undertaken through a combination of programs sponsored by the Department of Commerce and other Government agencies, and through cooperative research agreements with the private sector. ITS policy provides that work sponsored by other agencies results in contributions to and reinforcement of NTIA's overall program and must be directed toward supporting the goals of the Department of Commerce. Various Department of Defense components provide the majority of ITS' funding from other agencies. Other sponsors include the Department of Agriculture, the Department of Transportation, and the U.S. Information Agency.

Cooperative research agreements with such companies as U.S. West Advanced Technologies, Inc. and Telesis Technologies Laboratories, Inc., support technology transfer and commercialization of telecommunications products and services, which is a major goal of the Department of Commerce. ITS also undertakes cooperative research agreements with small, start-up companies such as Superconducting Core Technologies of Golden, Colorado to ensure the competitiveness of such entrepreneurial ventures with larger national concerns.

Because of its centralized Federal position, ITS is able to provide a cost-effective, expert resource that does not require duplication throughout many Federal agencies and industry. ITS provides scientific research and engineering which is critical to continued U.S. leadership in the provision of telecommunications and information equipment and services.

This progress report summarizes significant technical contributions made by ITS during fiscal year 1994 that have significance for both the public and private sector.



Organization Chart for the Institute for Telecommunication Sciences.

Radio Spectrum Measurement System Van Performing a Spectrum Survey near the Kent Narrows Bridge in Maryland, Virginia. **See RSMS Spectrum Surveys, Page 12.** *Photograph by F. Sanders.*

SPECTRUM PLANNING AND ASSESSMENT

The National Telecommunications and Information Administration (NTIA) is responsible for managing the radio spectrum allocated to the Federal Government. Part of NTIA's responsibility is to "... establish policies concerning spectrum assignment, allocation, and use, and provide the various departments and agencies with guidance to assure that their conduct of telecommunications activities is consistent with these policies." In support of these requirements, ITS conducts a variety of studies and field measurement activities directed toward ensuring efficient, effective, and equitable use of the radio spectrum resource. A prime objective of these analyses is to increase spectrum usefulness by developing ways to use presently congested portions of the spectrum more efficiently and to open up new portions of the spectrum for productive use.

In conjunction with these spectrum analyses, ITS supports NTIA's active role in developing and advocating the United States' position at various international spectrum allocation conferences. Decisions made at these conferences significantly affect the ways that the U.S. can use the radio frequency spectrum. U.S. positions at these conferences also help determine the ways that frequencies are used worldwide, which affects U.S. export market opportunities, as well as the compatibility and interoperability of global systems.

Through a variety of activities, ITS uses its scientific and engineering research expertise to develop computer programs and methodologies to assist the Federal Government in the productive use and efficient management of available spectrum. Since these methods are useful to the private sector as well, ITS has established a computerized method of transferring this technology to all interested parties on a reimbursable basis (see Telecommunications Analysis Services, page 46).

AREAS OF EMPHASIS:

ITU Radiocommunication Sector Activities
Includes projects funded by NTIA.

Domestic Spectrum Analysis - Fixed Services
Includes projects funded by NTIA.

Domestic Spectrum Analysis - Mobile Services
Includes projects funded by NTIA.

RSMS Spectrum Surveys
Includes projects funded by the Department of Defense, the National Oceanic and Atmospheric Administration, and NTIA.

Interference Resolution
Includes projects funded by NTIA.

Spectral Assessment of Government Systems
Includes projects funded by NTIA.

Spectrum Measurement Technology Development
Includes projects funded by the Department of Defense and NTIA.

ITU RADIOCOMMUNICATION SECTOR ACTIVITIES

OUTPUTS

- Technical standards supporting U.S. positions at radio conferences.
- Leadership of U.S. participation in key ITU-R Study Groups.
- Coordination of U.S. positions on issues related to ITU-R recommendations.

The first meeting of the International Telecommunication Union - Radiocommunication Sector (ITU-R) assembly was held in Geneva during November 1993. The ITU-R succeeds the International Consultative Radio Committee (CCIR), the ITU body responsible for radio system characteristics as they relate to international standards.

Due to the explosive international growth in both telecommunications technology and the demand for communication services, the ITU has restructured itself to provide more timely information and standards. Telecommunication services that used to take years of research and development are now developed and implemented much faster. Communication service providers are anxious to develop new services, to provide alternative forms of competition, and to let the market place determine the fate of the new services.

All radio communications services require spectrum to operate and the ITU must determine the conditions required for that operation in order to assign spectrum to the service. The electromagnetic spectrum has become crowded and, as a result, the ITU-R must provide guidance on how services can share spectrum and must mitigate interference among systems within the same service and between systems of different services. Finally, the ITU must provide direction to the services to develop standards of operation and compatibility.

The ITU-R has divided its work program into the following nine Study Groups; the first three Study Groups deal with spectrum utilization and propagation issues and the latter Study Groups are concerned with service-oriented issues:

- 1 - Spectrum management
- 2 - Interservice sharing and compatibility
- 3 - Radiowave propagation
- 4 - Fixed-satellite service
- 7 - Science services
- 8 - Mobile, radiodetermination, amateur, and related satellite services
- 9 - Fixed service
- 10 - Broadcasting service - sound
- 11 - Broadcasting service - television

Former Study Groups 5 (radiowave propagation in nonionized media) and 6 (radiowave propagation in ionized media) were consolidated into a new Study Group 3 with the task of addressing all issues relating to radiowave propagation.

Each of the Study Groups is further divided into Working Parties and Task Groups that study particular issues and develop documents that will lead to recommendations of the Study Group. The Working Parties and Task Groups lend a more continuous process to the development of recommendations than the former process, which required years of study and discussion before a recommendation could be adopted.

While the ITU-R uses international Study Groups that address specific areas of radio system technology, the U.S. has a corresponding set of national committees that prepare the U.S. input for consideration by the international committees. The particular topics treated by each Study Group vary to meet current needs and to reflect the topics that will be discussed at forthcoming radio conferences. The recommendations of the ITU-R are used to establish technical criteria that are the basis for spectrum allocation decisions and spectrum use, both globally and regionally. In addition, the agreements reached at the World Administrative Radio Conferences have the status of international treaties for the United States. Therefore, it is important to the U.S. that ITU-R documents accurately reflect the U.S. position on important spectrum policy matters.

ITS is an active participant in both international and national committee work. One ITS staff member holds the office of international chairman of a Working Party and several ITS staff participate in the committee meetings of the international Study Group. Two ITS staff members are U.S. Study Group chairmen and many other ITS staff members participate in U.S. Study Group activities. One ITS staff member is an international Rapporteur on short-path radiowave propagation issues relating to the service needs of systems such as personal communication systems (PCS) and wireless local area networks.

If many services desire the same bands in which to operate, how can the ITU-R satisfy all desires and needs? What are the trends in radio communications technology related to these problems? What can be done to encourage the best use of the spectrum for the maximum benefits? Sharing of spectrum by providers of the same service is the first step. The separate channels which comprise the spectrum have historically been used by authorized users. When the user was not transmitting or receiving, the channel would be idle and in a sense, wasted. The ability to trunk several authorized users on a few channels makes more efficient use of the spectrum. Techniques such as time division multiple access and code division multiple access provide for more efficient use of the spectrum. However, technology may allow even more sharing. Systems are beginning to have distributed intelligence, meaning smart transmitters and smart receivers. If two systems from two different services were to share the same spectrum, there would need to be some form of etiquette to prevent interference between the systems. One technique is to "listen before talk," where one system wanting access to the channel listens to determine if there is any user already present. If the channel is clear, the system transmits. This scheme could be used between land mobile services and fixed services (e.g., microwave links) for example. Various Study Groups are evaluating different aspects of these techniques to increase spectrum efficiency.

A current issue for the ITU-R is the development of the Future Public Land Mobile Telecommunications System (FPLMTS) of which PCS may be considered as a first phase. The Figure below shows the availability and interconnectivity of FPLMTS from locations completely within an office to locations in the world serviced only by satellites. Spectrum utilization, propagation considerations, and system operation problems are challenges to providing telecommunications service anywhere at any time. ITS plays a major role in supporting the U.S. position on FPLMTS development and implementation.

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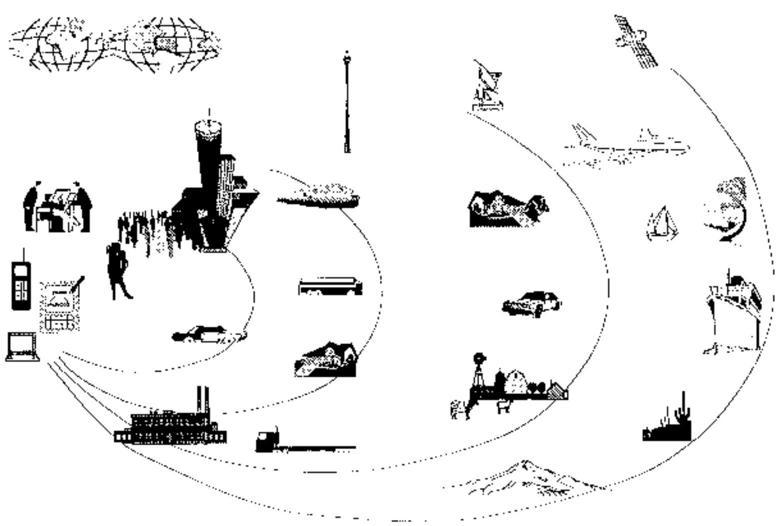

Applications and Environment for the Future Public Land Mobile Telecommunications System.

DOMESTIC SPECTRUM ANALYSIS-FIXED SERVICES

OUTPUTS

- Contributions to U.S. Spectrum Requirements Report.
- Update on fixed services study.
- Report on spectrum capacity gains.

NTIA must plan for the future as it manages the portion of the radio frequency spectrum used by the Federal Government. A three-year project to predict future spectrum requirements is coming to fruition, with the release of an NTIA summary report in early FY 95. ITS has been assisting in this work with an analysis of the fixed services in the U.S.

For decades the fixed services had been expected to carry most long-range telecommunications, implemented especially as point-to-point microwave links. The individual links are limited to line-of-sight range, but links were assembled into transcontinental chains that carried thousands of narrowband voice and data circuits or wideband circuits carrying television. More than half of the U.S. spectrum below 30 GHz was allocated on a primary basis to meet the great demand for the fixed services.

Recently, at least for common carriers, optical fiber has absorbed much of the growth in new telecommunications capacity (Figure 1). In the 1993 ITS Staff Study on fixed services, we calculated that in 1992, fiber links added 23 times more new capacity than microwave links. Based on license counts at the end of 1991, we confidently predicted that overall use of microwaves would begin to decrease rapidly as more circuits were moved to fiber.

Such predictions are needed for long-term strategic planning of spectrum allocations. ITS is assisting with the preparation of an NTIA report on U.S. spectrum requirements, which will outline the expected changes in spectrum requirements over the next ten years. The predicted decline in the use of fixed services is significant, since these services may represent the best place to obtain additional spectrum for rapidly growing mobile services. This has already happened to some extent; the Federal Communications Commission (FCC) has reallocated 220 MHz of fixed spectrum near 2 GHz for personal communication services (PCS) and other unspecified mobile or mobile-satellite services. In addition, the Federal Government has recently proposed that 200 MHz of Federal spectrum be turned over to the FCC for reallocation for non-Federal purposes. Much of the 200 MHz was originally allocated for fixed services; the FCC is expected to allocate most of it for mobile services.

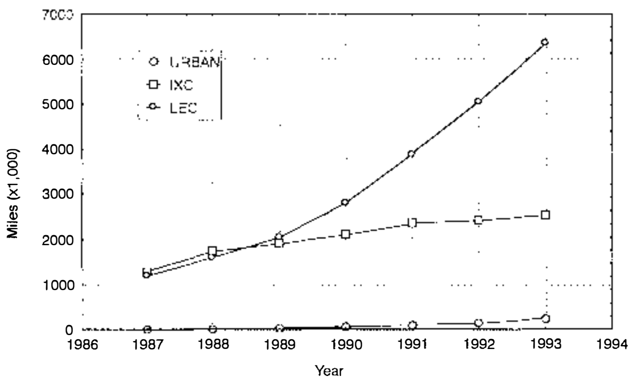

Figure 1. Growth of Optical Fiber Services.

Unfortunately, predications do not always come true, even if there are iron-clad supporting arguments. Updates to the ITS fixed services staff study considered two more years of frequency license history. Figure 2 shows a dramatic change of direction for frequency license counts, beginning in 1991. Ironically, the chief market factor driving the increase in common carrier fixed microwave licenses is the rapid growth in mobile services.

Many cellular telephone sites are connected with a network of microwave links. Unlike fiber, microwave links can be established almost instantly and are easily aimed to accommodate new sites in the constantly growing cellular networks. Microwave links also tend to be cheaper than fiber for circuits carrying less traffic than a DS-3 link (45 Mb/s), while fiber is cheaper for links carrying many DS-3 circuits.

Whether fiber will eventually replace many of these microwave links is difficult to predict, partly because the business world is apparently continually

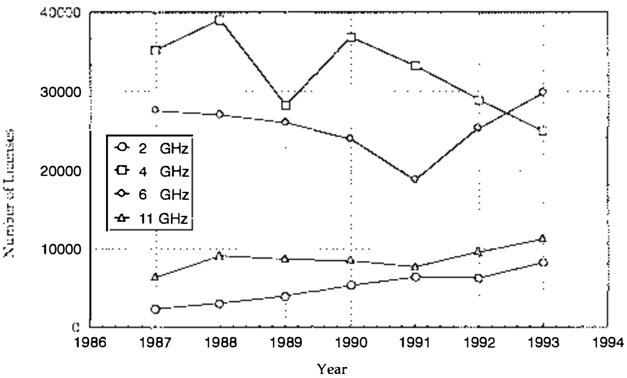

Figure 2. Frequency Licenses in the Common Carrier Bands.

rethinking its fiber strategies. Mergers between fiber-based telephone companies and fiber-based cable television companies are announced, then cancelled (e.g., Bell Atlantic-TCI). Fiber-based long-distance companies are merging with cellular companies (e.g., AT&T-McCaw). Telephone companies are planning to use fiber for pay television distribution; cable television companies are planning to use fiber systems to provide telephone service. Independent urban fiber companies are still small, but are expanding rapidly. The fiber-based National Information Infrastructure is a national priority. Undersea fiber cables using soliton techniques and optical amplifiers are greatly increasing international cable capacity. However, it is still uncertain to what extent fiber will replace microwave links. The answer is crucial for predicting how much fixed microwave spectrum will be needed to support planned PCS networks.

Spectrum shortages have always been a cause for worry to the entrepreneur, who may not be able to find sufficient spectrum to operate a new system. With all of the new demands on spectrum (e.g., personal communication services, mobile satellites, high definition television, and intelligent vehicle highway systems) one might legitimately worry about the future of radio communications. Which services will have to be set aside to make way for the new ones? A recent ITS paper suggests that spectrum crowding will not necessarily get worse. Spectrum capacity (i.e., the ability of spectrum to carry communications) is also growing rapidly—possibly faster than the demand for spectrum based services. The growth in spectrum capacity comes from:

- the increasing use of short-range systems (providing opportunities for frequency re-use, by a factor of 25),
- the use of digital compression for video and audio channels (allowing more channels to be carried in a given bandwidth, by a factor of three),
- the decreased cost of higher frequency components (allowing consumer use of higher frequencies, by a factor of five), and
- the reallocation of frequencies from Federal/ military bands and less-needed services (providing an increase in spectrum availability by a factor of 1.3).

These factors are not mutually exclusive; that is, many of them can apply at the same time, so that they are somewhat multiplicative. Multiplied together, these factors could provide an increase in spectrum capacity of almost 500 times, in the next 10-15 years. An increase in capacity must be compared to the projected increase in demand; also other factors, such as regulatory actions, must be considered before one can declare the shortage over.

RECENT ITS PUBLICATIONS

A Preliminary Look at Spectrum Requirements for the Fixed Services (by Matheson and Steele).

Spectrum Stretching: Adjusting to an Age of Plenty (by Matheson).

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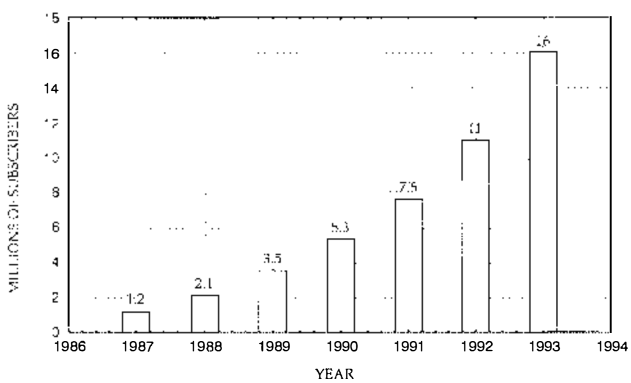
DOMESTIC SPECTRUM ANALYSIS-MOBILE SERVICES

OUTPUTS

- Colorado APCO-25 coordination.
- Mobile Spectrum Efficiency Report.
- Mobile Spectrum Efficiency Report to Congress.
- IVHS spectrum requirements.

The Wireless Age is here, bringing with it an explosion in the number of radio transmitters in use in the U.S. For example, the Figure below shows that the number of cellular telephones has been increasing at approximately 30% a year for the last 10 years, and there are now about 16 million in the U.S. The number of Federal and non-Federal land mobile radios is growing at a rate of 5-10% a year. Pagers and cordless phones add another 80 million radios to the total. Three major new services are being added to the American scene in the next few years, including mobile satellite services, intelligent vehicle highway systems (IVHS), and personal communication services (PCS). Yet, no "new" frequencies have been generated that can handle these additional transmitters. What can be done to accommodate the millions of new radios? ITS activities in domestic spectrum analysis for the mobile services addressed this issue in several areas.



Growth in U.S. Cellular Telephone Users.

Last year, Congress asked NTIA to prepare a plan to make Federal use of mobile radio at least as efficient as private and commercial use. That report was published early in FY 94 as NTIA Report 93-300. ITS participated in developing some basic descriptions of how Federal mobile systems operated and provided a methodology to compare the spectrum efficiency of such systems. Implementation of the recommendations of that report continued in FY 94 within the Interdepartmental Radio Advisory Committee Ad Hoc 211 by NTIA's Office of Spectrum Management.

The work on mobile spectrum efficiency was extended and published as NTIA Report 94-311 this year. This report developed some surprising information, including data showing that the efficiency ratio between the most spectrum-efficient and least spectrum-efficient systems studied was about a million-to-one. The Table opposite summarizes some of the spectrum efficiency factors from that report, which compares the spectrum efficiency of 24 contemporary land mobile radio systems—using a 15-kHz FM analog dispatch mobile radio as a reference system.

The Table shows the "Best" (most efficient) and "Worst" (least efficient) mobile radio system, when evaluated for certain factors. "Channels Required" deals with how many radio channels a voice circuit requires (e.g., full-duplex requires two simultaneous channels) "Queuing Efficiency" is set to a value of five for all trunked systems. "Bandwidth per Channel" indicates how many kHz are needed to transmit a voice channel. "Re-use Efficiency" (or range efficiency) indicates how many times a frequency can be reused within the 80-km radius of a typical mobile radio signal. The "Ratio" column gives the ratio between the best and worse systems for that particular factor (e.g., the worst system considered required 10.5 times more bandwidth to transmit a voice channel than the best system). The Table shows that the most important spectrum efficiency factor was the frequency re-use distance of a system. Some short-range systems were 350,000 times more efficient than some long-range systems. An obvious conclusion from this work: If the spectrum is getting crowded, use a more efficient system—there is a lot of room for improvement.

ITS assisted the Federal Highway Administration in planning what spectrum will be needed by the IVHS program. Through participation in a combination of standards bodies and national meetings, ITS helped to determine which IVHS functions needed additional frequencies and which ones could be met in existing frequency bands (see Intelligent Vehicle Highway System, page 40). The use of existing frequency bands and services will permit many IVHS services to be implemented much earlier and at lower cost. Moreover, frequencies that might have been used for IVHS can be used elsewhere.

The public safety and law enforcement agencies require somewhat different services than commercial users. In particular, these agencies often need encryption (or at least privacy) and may need to invoke a priority to ensure that the most important messages are relayed in emergency situations. These functions, and others, are being designed into a joint Federal/ private standard called APCO Project 25 (APCO-25). APCO-25 radios will provide fully-encrypted digital voice features, using a 12.5-kHz bandwidth channel. These radios are expected to be widely used throughout public safety and Federal communities. APCO-25 radios will be supported by multisite trunked radio networks, and will possibly be shared by multiple agencies. It is expected that such systems would soon be used for a large number of specialized applications, including faxed "mug shots" and fingerprints, connections to national crime databases, and car license information.

Because these systems can be efficiently shared by many users, several states are planning to implement statewide APCO-25 trunked mobile systems for state and municipal communications. NTIA promotes sharing trunked mobile systems among various Federal users and is trying to develop improved procedures that allow easier and more productive sharing. ITS is working with groups in the state of Colorado to help specify functional requirements and organizational structures that would more easily facilitate shared use of a proposed Colorado system. An ITS staff member chairs the APCO-25 Encryption Task Group.

As a result of the recent National Performance Review, the Department of Treasury and the Department of Justice were instructed to combine the radio systems of a dozen separate agencies into a single nationwide network. ITS provides support to the recently established Federal Law Enforcement Wireless Users Group (FLEWUG). Initial planning points toward the use of a combined nationwide APCO-25 system. It will be interesting to see to what extent this nationwide system provides services to other Federal agencies, or even shares services with non-Federal systems like the Colorado system. If the details of system administration can be worked out, there may be considerable advantages in bringing many noncritical users onto the system, so that a larger traffic capacity can be tapped during emergencies.

RECENT ITS PUBLICATIONS

Land Mobile Spectrum Efficiency: A Plan for Federal Government Agencies to Use More Spectrum-Efficient Technologies (by Cohen, Roosa, Matheson, Kitzmiller, and Patrick).

A Survey of Relative Spectrum Efficiency of Mobile Voice Communication Systems (by Matheson).

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Summary of Mobile Spectrum Efficiencies

Factors	Worst	Best	Ratio
Channels Required	0.5	1	2
Queuing Efficiency	1	5	5
Bandwidth per Channel	44 kHz	4.2 kHz	10.5
Re-use Efficiency	0.008	2,850	350,000
Composite	0.005	5,075	1 million

RSMS SPECTRUM SURVEYS

OUTPUTS

- Spectrum survey in Denver, CO from 100 MHz to 19.7 GHz.
- Spectrum survey in Denver, CO across the ISM band (2400-2500 MHz).

In support of an ongoing program to determine patterns of spectrum use and occupancy in the U.S., the ITS Radio Spectrum Measurement System (RSMS) was used to perform broadband spectrum surveys in the Denver area. Previous surveys have been performed during the past twenty years in most major U.S. metropolitan centers. The Denver spectrum survey was the first to utilize recently upgraded RSMS capabilities for spectrum measurements.

The most comprehensive surveys measured levels and types of activity in the spectrum across a frequency range of 100 MHz to 19.7 GHz. All bands between these frequencies were monitored for a period of two weeks from a hill in the Denver area. Measurement algorithms and parameters were tailored to effectively intercept the traffic that is characteristic of each band (i.e., radar intercept algorithms were used in radar bands and mobile radio intercept algorithms were used in mobile radio bands). Two systems took simultaneous measurements in the 100- to 1000-MHz range and in the 1- to 19.7-GHz range. This cut the time required for the survey in half, compared to what would have been required if only one system had been used.

At the end of the two-week survey, the data was returned to Boulder, CO for analysis and report production. Analysis involved such activities as "cuming," where the cumulative activity in each band during the two-week measurement period was processed from the raw data. The "cumes" show the maximum, minimum, and mean levels of activity in each band during the site survey period. Samples of these data are shown in Figure 1. The full set of "cumed" data from the survey in Denver, CO will be released as a technical report in 1995.

Additional surveys were performed in the Denver area to determine the levels and types of occupancy of the spectrum in the industrial, scientific, and medical (ISM) band of 2400-2500 MHz, and adjacent parts of the spectrum. This survey of the spectrum occupied by microwave oven emissions was a follow-up to earlier measurements taken of individual microwave ovens.

The aggregate-activity ISM band measurements showed that background radiation from devices in the band is always present. Figure 2 shows a two-week "cume" of activity in this part of the spectrum measured at a suburban location. The high bulge between 2400-2500 MHz represents maximum, minimum, and mean emissions from ISM devices, primarily microwave ovens, as measured from a high hill in the suburbs. The emissions near 2450 MHz are noise-like in character. Similar measurements were performed in downtown locations and in the mountains west of Denver, with similar results. The aggregate effect of microwave ovens and other ISM-band devices measured in these surveys can be used to determine the impact ISM devices may be expected to have on new technologies used in the ISM and adjacent bands. This data may also be used by system designers to make new systems resilient to interference from ISM-type emissions.

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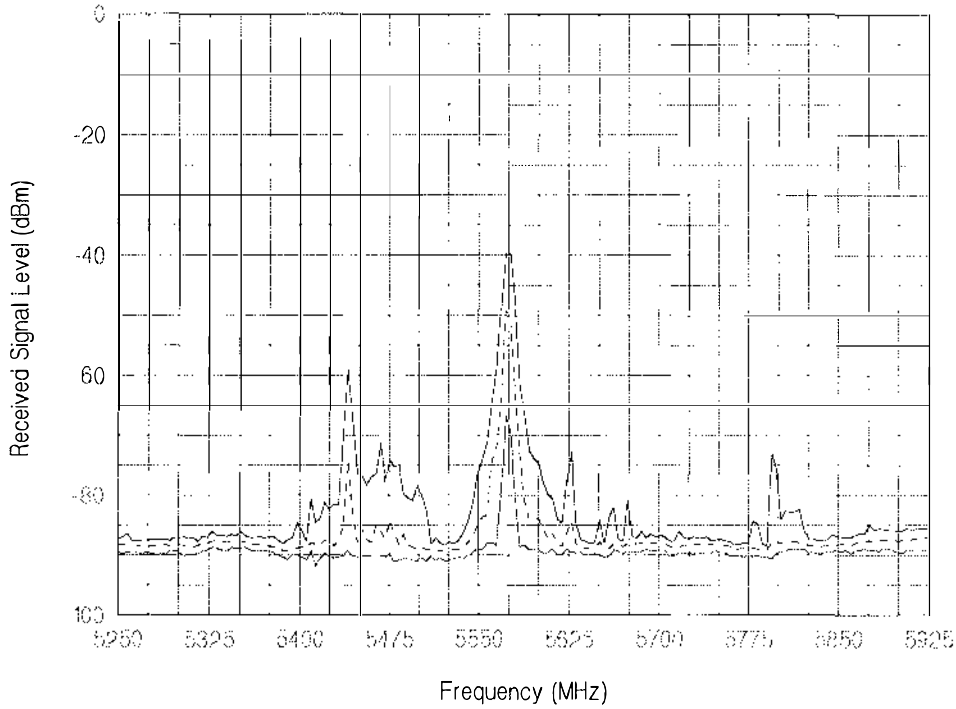

Figure 1. Example "Cumed" Data from a Two-week Spectrum Survey near Denver, Colorado.

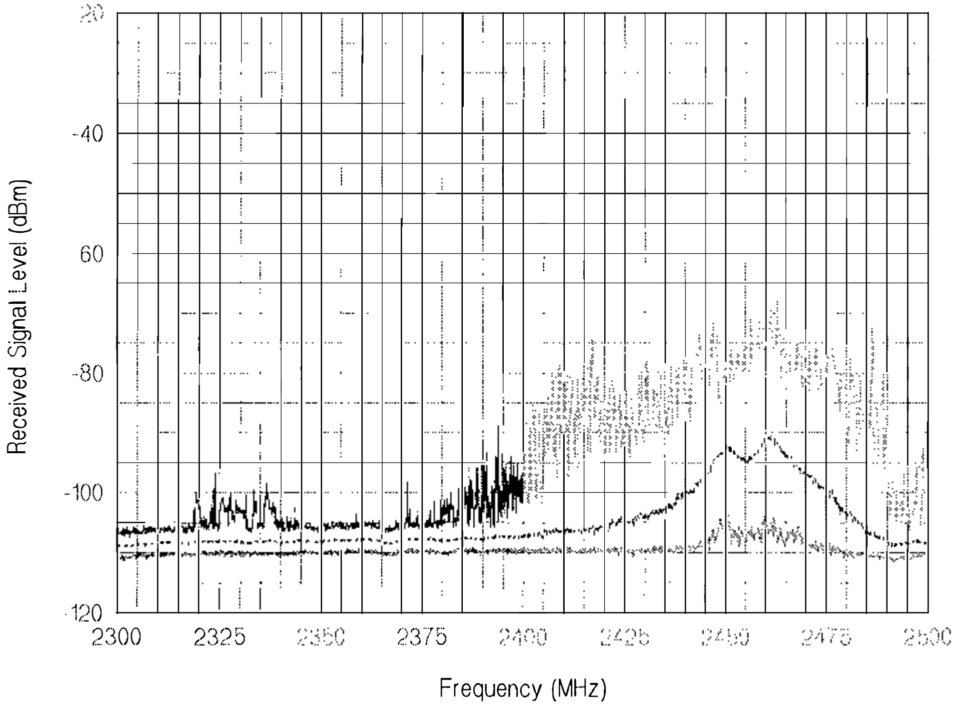

Figure 2. "Cumed" Data from a Spectrum Survey of the Industrial, Scientific, and Medical Band near Denver, Colorado.

INTERFERENCE RESOLUTION

OUTPUTS

- Characterization of electromagnetic compatibility and resolution of interference problems between Government communication systems.

In support of spectrum management policy, the Spectrum Use and Measurement Group at ITS uses the Radio Spectrum Measurement System (RSMS) to perform interference resolution and electromagnetic compatibility studies. Since the RSMS is a mobile measurement system, it is specially suited to make measurements at locations where suspected interference or incompatibilities exist.

In FY 94, the RSMS was involved in two separate efforts to characterize compatibility between Government communication systems. The first was a compatibility study between the National Weather Service (NWS) wind profiler radar, and the United States Air Force's (USAF) PAVE PAWS radar. The Wind Profiler is a wind measurement tool being deployed throughout the United States. It is likely to be licensed with a center frequency near that of the PAVE PAWS radar. Before the wind profilers could be deployed, a coordination distance had to be determined for their placement near existing PAVE PAWS installations. To determine this distance, measurements were made to determine the impact of wind profiler emissions on the PAVE PAWS system. This effort was completed during the summer of FY 94. NWS and the National Oceanic and Atmospheric Administration (NOAA) provided a wind profiler simulator that was used to characterize the impact of the radar on PAVE PAWS. ITS provided field strength measurements of the simulator emissions at the PAVE PAWS receive antenna. Based on these measurements, the NWS and USAF agreed on a coordination distance for the operation of these two systems.

The Spectrum Use and Measurements Group completed a second compatibility study to determine the effect of a synthetic aperture radar operated by the Jet Propulsion Laboratory (JPL) on communication systems used by the United States Department of Justice (DOJ). The radar is similar to the SIR-C radar carried aboard the Space Shuttle, operating in three separate radiolocation bands simultaneously (Figures 1, 2 and 3). This particular version is mounted on a Boeing 707 aircraft. ITS performed measurements to characterize the emissions of the radar in each emission band, using multiple measurement bandwidths. Additional tests were performed to determine the impact of the radar emissions on the DOJ systems by adjusting relative carrier levels. This measurement methodology allowed ITS and JPL engineers to see the radar as a communications system does, giving a good indication of the interference potential between the systems. The results of the study were used to define coordination contours and procedures for the mutual operation of the two systems.

RECENT ITS PUBLICATION

Measurements of Wind Profiler EMC Characteristics (by Law, Sanders, Patrick, and Richmond).

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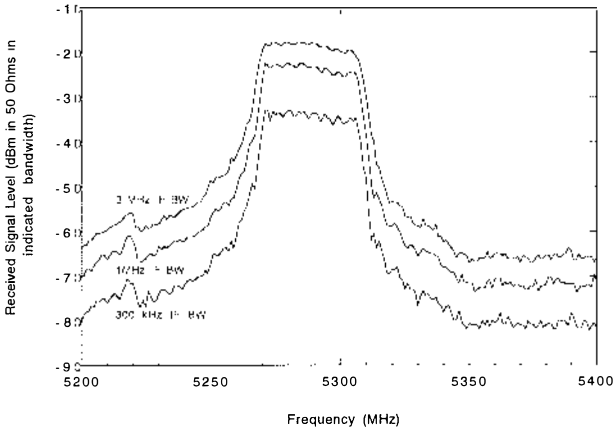

Figure 1. Radar C-Band Signal Level Measurements of SIR-C Radar.

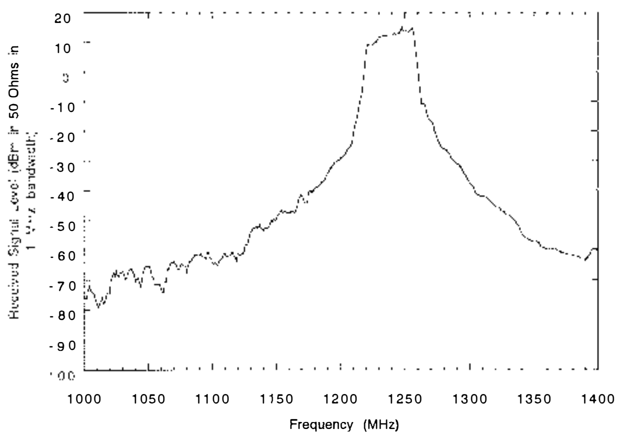

Figure 2. Radar L-Band Signal Level Measurements of SIR-C Radar.

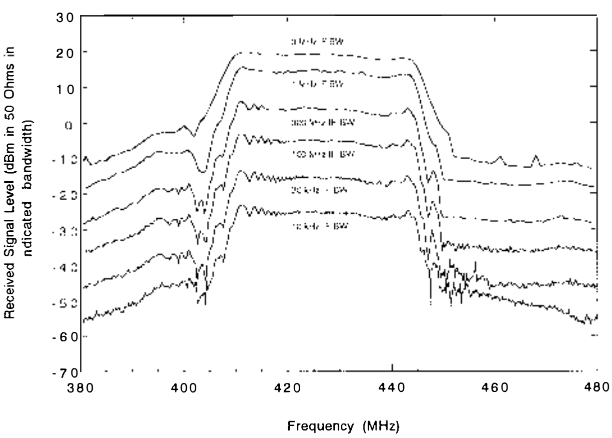

Figure 3. Radar P-Band Signal Level Measurements of SIR-C Radar.

SPECTRAL ASSESSMENT OF GOVERNMENT SYSTEMS

OUTPUTS

- Spectral emission measurements of HF radios being considered for Federal Government acquisition.
- Spectral emission measurements of NOAA's wind profiler radar system.

ITS routinely performs measurements on the emission characteristics of new transmitter equipment under consideration for acquisition by Federal agencies. These measurements determine the spectral occupancy and time waveform outputs of the equipment. The data is used by the Office of Spectrum Management (OSM) and other agencies to determine the conformance of the equipment with current standards, and the expected degree of compatibility of these systems with other systems already occupying the spectrum. Some measurements are performed to verify that equipment being installed in foreign countries (or being considered for purchase by foreign countries) meets applicable standards.

This year, ITS measured spectral emissions from two systems being purchased by the Federal Government. The measurements were performed to determine the conformance of the systems with NTIA regulations for spectral emissions, and also to determine the compatibility of these systems with existing systems occupying the same parts of the spectrum.

The first of these was a set of HF radios being considered for acquisition by a number of Government agencies. Each of the radios, which were voice-communication systems, was tested at the ITS laboratory in Boulder, Colorado to determine the spectral envelope of emissions near the center frequencies, and also the relative amplitudes of the harmonics, through the twentieth harmonic. The ITS data was used to determine which radio should be acquired by the agencies. Observations on the usefulness and applicability of some types of measurements to current NTIA and Federal Communications Commission standards were also used to suggest changes in current NTIA standards.

The second set of measurements was performed on a new type of wind profiler radar for a system to be deployed and operated by the National Oceanic and Atmospheric Administration (NOAA). The NOAA system is expected to eventually provide coverage across much of the continental U.S. and Alaska, with data being transmitted to atmospheric researchers, the Federal Aviation Administration, and the National Weather Service.

The emission spectra of this radar were measured in two operational modes. The radar currently operates at frequencies near 404 MHz, but production systems will operate at 449 MHz. This means that the profilers will share spectrum with high-powered, long-range radars including space tracking, air search, and strategic early warning systems. The measurements were used to determine the compatibility of this type of radar with such existing systems in the 420- to 450-MHz portion of the spectrum. These spectra are shown in Figures 1 and 2. The results of the full set of tests, measurements and analysis are presented in NTIA Report 93-301.

The wind profiler measurements also are being used to develop a new Radar Spectrum Engineering Criterion (RSEC), which specifies the maximum spurious emission levels permitted from any type of radar operated by the U.S. Government. The criterion currently provides restrictions on the emissions of weather radars, air traffic control radars, and all other air and space search and tracking systems. No category of the RSEC existed for wind profilers, and the ITS measurements provided data that demonstrated the current state-of-the-art in spectrum conservation by this type of transmitter. Based on these measurements, the wind profiler RSEC is expected to be the most conservative of the RSEC standards thus far.

RECENT ITS PUBLICATION

Measurements of Wind Profiler EMC Characteristics (by Law, Sanders, Patrick, and Richmond).

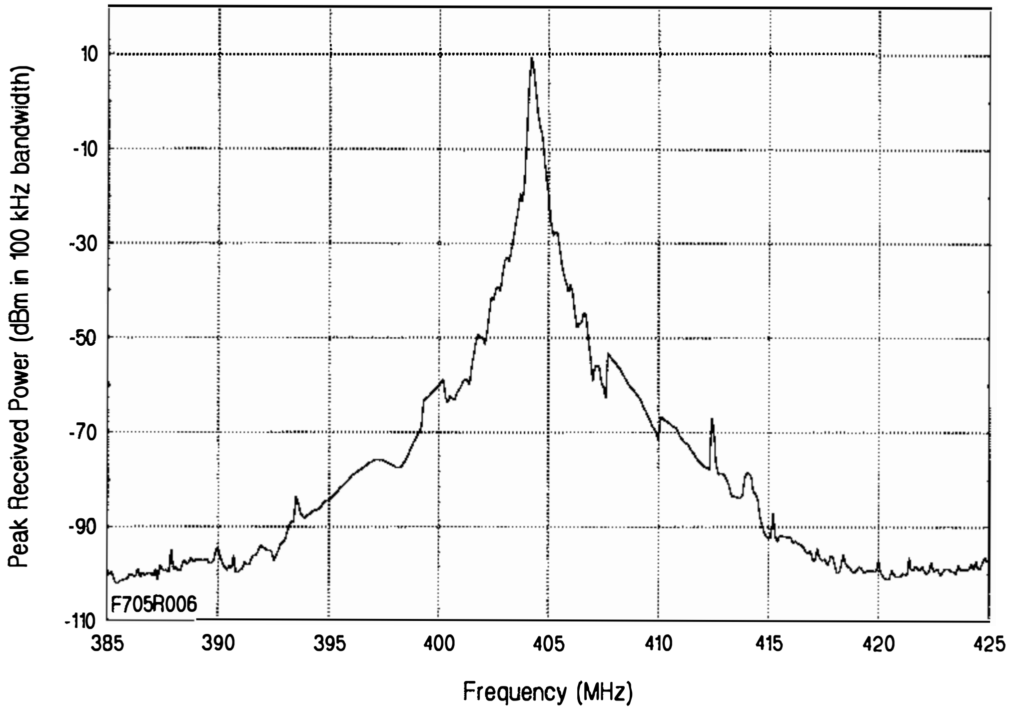

Figure 1. Wind Profiler Short-pulse Radiated Spectrum Envelope.

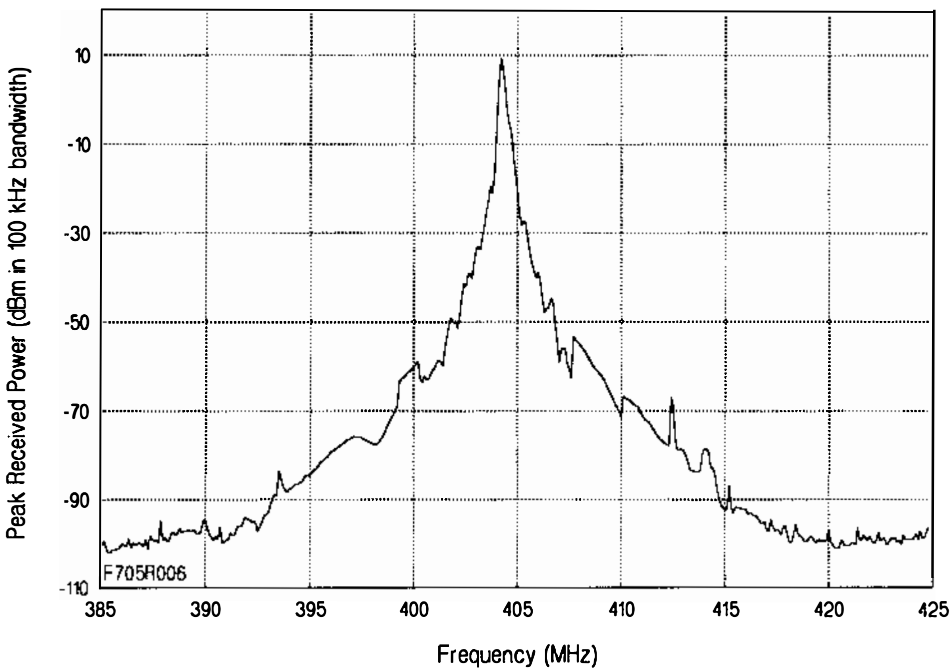

Figure 2. Wind Profiler Long-pulse Radiated Spectrum Envelope.

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SPECTRUM MEASUREMENT TECHNOLOGY DEVELOPMENT

OUTPUTS

- Continued development and enhancement of software for mobile and compact Radio Spectrum Measurement Systems.
- Evaluation of commercial hardware and software products for use in Radio Spectrum Measurement Systems.
- A frequency monitoring and direction finding system for the Yuma Proving Grounds.

ITS is continually developing and assessing new methods and instrumentation for detecting signals and measuring radio spectrum occupancy. By keeping at the forefront of radio spectrum measurement technology, ITS is able to provide the data necessary for effective radio spectrum regulation and management. This technology is also made available to other agencies through use of the ITS Radio Spectrum Measurement System (RSMS) and through the development of specialized measurement systems.

Advancements in compactness enable the rapid and easy deployment of sophisticated measurement systems. Control techniques have been developed and improved, simplifying the assembly of measurement systems from commercial off-the-shelf instrumentation. Custom, versatile interface boards have been designed to provide rapid system assembly and deployment. Plasma touch-screen controllers are adaptable to specialized configurations while providing an easily understood and user-friendly interface to the measurement hardware.

The RSMS mobile and suitcase (CRSMS) systems (see the photograph) have matured to a level of providing proven technology to enhance the sensitivity and selectivity of measurement systems. Commercial off-the-shelf hardware, with a minimum of custom devices, provide tracking filters that assure the integrity of measurements by reducing or eliminating interference from nearby high-power radio emitters. Lightweight components expand the ability to place systems in remote locations. System automation enables the operator to achieve extended dynamic range by manipulating the system gain and attenuation at the appropriate times.

Software, developed over the past several years, integrates the RSMS mobile and CRSMS portable instrumentation into easy-to-use, effective measurement systems. It provides the user with an automated capability in performing spectrum measurements. This software has undergone considerable testing, modification, and use by the RSMS teams. This software is provided to other agencies at the cost of license fees for the development libraries. These agencies use the software in their applications, provide ITS with feedback, or request additional capabilities. Work continues in the development, enhancement of capabilities, and reliability of this software.

Specialized software products have also been developed for systems that go beyond the routine spectrum measurements normally required. Such custom products have linked assorted instrumentation in order to achieve unique and extremely specialized capabilities that range from system testing to antenna calibration and remote monitoring.

Meanwhile other commercial hardware and software products are continually being evaluated as to their potential use with the RSMS and other systems. Some of these products may provide the types of measurement capabilities required by the RSMS teams in a mature operating platform. Often, RSMS requirements are more than off-the-shelf products can offer. Discussions with manufacturers may result in agreements to combine their talents with our measurement expertise to develop products to meet these requirements.

Special applications require different operating capabilities, ranging from operation within environmental restrictions to drop-in remote solar-powered capability. A system designed this year for Yuma Proving Grounds addressed several unique problems.

Yuma Proving Grounds required a frequency monitoring and direction-finding (DF) system that could be operated from a remote location away from potential interferers such as RF transmitters and repeaters. The facility required the capability to track radio activity in the region. Their proximity to the southern border of the United States and neighboring states caused interference from unlicensed radio use.

The only suitable location for installation on the Yuma range was a remote mountain top 2,000 feet above the desert floor. No commercial power was available, and access was only via helicopter from the base airport. This presented unique challenges for a prototype system. Not only did the hardware need to be straightforward in design, but the system needed to include facilities for recovering from a programming error or other fault.

The assembled system consisted of a primary direction finding system that covered the frequency range of 20 MHz to 1.3 GHz. A spectrum analyzer extended the frequency coverage up to 26.5 GHz, which acted as a downconverter to the primary DF system. Additional antennas and control circuitry extended the DF functions to the higher frequencies. A microwave link and digital modems provided control from remote locations. Batteries and solar panels provided fully-isolated, 24-hour operation.

This system also performs spectrum and modulation analysis of signals. With the antenna system switched to an omnidirectional mode, the spectrum analyzer provides the conventional frequency- and time-domain modes of analysis. The system is controlled by a computer integral to the remote station.

Through the microwave link, the system can be operated as if the operator were on the mountain. The microwave links connect to two standard telephone lines; one line is for standard computer/modem control while the other line monitors the audio from the remote receiver and provides touch-tone system reboot capability. Thus the system is accessible from any MS-DOS computer with remote software, whether fixed using regular telephone service or mobile using a cellular telephone. To track a bogus signal, the mountain remote system can be operated from the mobile Desert RAT spectrum measurement system, which is a mobile frequency monitoring system designed, procured, and configured by ITS.

These features provide remote operating and programming capabilities that allow data collection in real time or independent timed operation. Software has been provided to monitor specific channels and log time and frequency of signals that exceed a preset threshold. Data can be downloaded to the central control station. New programs can be designed and uploaded on the system, thus requiring only occasional helicopter access for maintenance.

The latest technology in measurement instrumentation was used to provide the best operational duration for the expended cost. Discrete instrument power control along with power and temperature monitoring enable the remote operator to select the best operation for the power at hand.

Specialized systems such as these provide other agencies with capabilities that are critical to test range operation. In this day of agency downsizing, such systems enable a minimal staff to meet frequency management needs.

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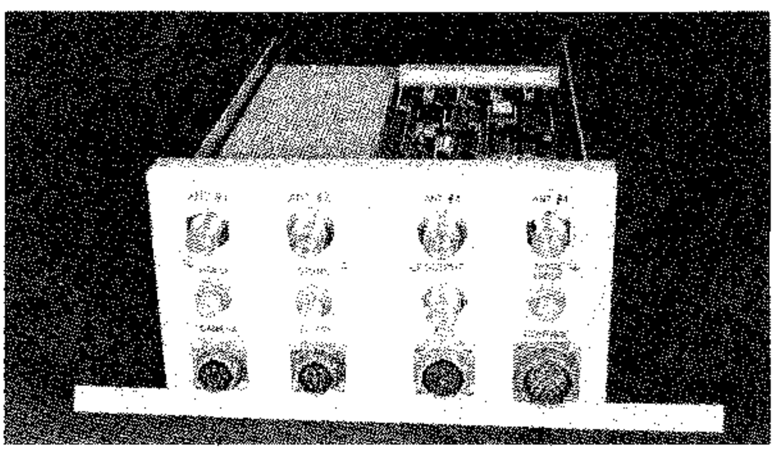


The Compact Radio Spectrum Measurement System. *Photograph by D. Sutherland.*

Opening Plenary of the ITU-T Study Group 13 in Geneva, Switzerland. Randy Bloomfield of ITS is at Far Right. See ITU Telecommunications Standards Activities, page 22. *Photgraph Courtesy of the ITU.*

TELECOMMUNICATIONS STANDARDS DEVELOPMENT

The Institute contributes significantly to the development and application of national and international telecommunications standards. These standards provide a technological framework for the evolving National Information Infrastructure, promote healthy competition in telecommunications products and services, and expand international trade opportunities for U.S. telecommunications firms.

During FY 94, ITS placed special emphasis on developing standards for Broadband Integrated Services Digital Networks and supporting applied research in the areas of audio, video, data, and multimedia communications quality. These efforts enhance infrastructure development and promote efficient matching of emerging telecommunications and information technologies and services with user needs.

Through its leadership roles and focused technical contributions, ITS assists in the development of key Federal, national, and international standards. Institute staff chair and contribute strongly to standardization activities in the ANSI-accredited Standards Committee T1 (Telecommunications), in the International Telecommunication Union-Telecommunication Standardization Sector (ITU-T), and in other national and international telecommunications standardization committees. The technical standards and recommendations developed in these forums frequently become the blueprints for future technology development and can influence billions of dollars in telecommunications research and development investments on a worldwide basis.

AREAS OF EMPHASIS:

ITU Telecommunication Standardization Sector Activities
Includes projects funded by NTIA.

Objective Audio Quality Research and Standards Development
Includes projects funded by NTIA and the National Communications System.

Video Quality Standards Development
Includes projects funded by NTIA and the National Communications System.

Digital Networks Program
Includes projects funded by NTIA and the National Communications System.

Telecommunication and Information-Processing Terminology Standards
Includes projects funded by the National Communications System.

Personal Communication Services Standards Support
Includes projects funded by NTIA.

Wireless Local Area Network Standards Support
Includes projects funded by NTIA.

Telecommunications Transmission Media Technology Studies
Includes projects funded by the National Communications System.

ITU TELECOMMUNICATION STANDARDIZATION SECTOR ACTIVITIES

OUTPUTS

- U.S. and international ITU-T leadership.
- Technical contributions.
- Proposed ITU-T recommendations.

The International Telecommunication Union-Telecommunication Standardization Sector (ITU-T) plays a preeminent role in the cooperative planning of public telecommunications systems and services on a worldwide basis. The technical standards ("Recommendations") developed in the ITU-T have substantial impact on both the evolution of the U.S. telecommunications infrastructure and the international competitiveness of U.S. telecommunications products and services. The Institute supports ITU-T activities by leading U.S. preparatory committees and international work groups, preparing technical contributions to advance ITU-T standards development, and drafting proposed Recommendations on topics of importance to U.S. interests.

The Institute provides strong support to the U.S. Department of State in leading the U.S. Organization for the ITU-T. During FY 94, Institute personnel served on the U.S. International Telecommunications Advisory Committee (formerly the ITU-T National Committee), which guides overall U.S. participation in ITU-T activities, and provided leadership for U.S. ITU-T Study Group B, which approves and presents U.S. contributions to the ITU-T on emerging Broadband Integrated Services Digital Networks (B-ISDNs), personal communication services (PCS), and intelligent networks (INs). B-ISDNs will provide integrated video, audio, and data communications using ultrahigh-speed transmission systems and cell-based Asynchronous Transfer Mode (ATM) switching systems; they are expected to provide a principal basis for the emerging U.S. National Information Infrastructure (NII) and the Global Information Infrastructure (GII) proposed by U.S. representatives at the ITU World Telecommunications Development Conference in March 1994. Related PCS and IN capabilities will enable subscribers to establish multimedia communications among cordless portable or fixed personal terminals located anywhere in the world in a matter of seconds, and to establish custom-tailored communication profiles to meet business and personal needs. ITU-T Recommendations are the "blueprints" for B-ISDN, PCS, and IN services, and thus strongly influence long-term telecommunications investments on a worldwide basis. The Institute's responsibilities for the ITU-T Study Group B include organization and conduct of U.S. ITU-T preparatory meetings and leadership of the U.S. Delegations to international meetings of ITU-T Study Group 13 (General Network Aspects).

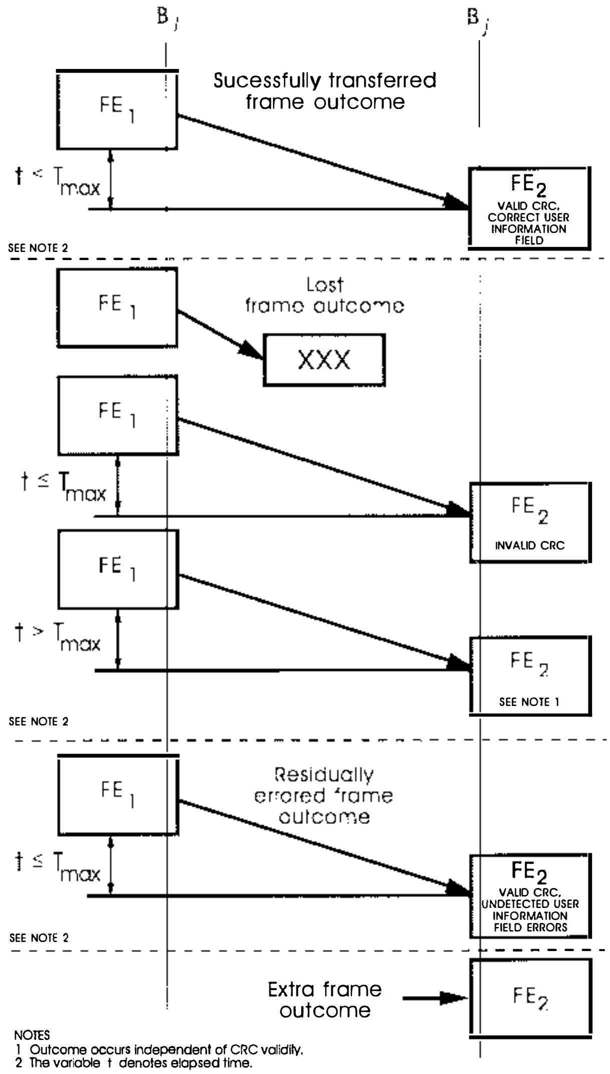
The Institute also provides leadership in ITU-T and ANSI-accredited standards committees whose work is relevant to Department of Commerce goals. During FY 94, Institute representatives: 1) continued leadership of ITU-T Working Party 4/13, 2) concluded a decade of national leadership in the ANSI-accredited T1 (Telecommunications) Standards Committee's Working Group T1A1.3, 3) assumed a broader role in leadership of T1A1, and 4) provided organizational and administrative assistance to T1S1. Working Party 4/13 develops performance specification and measurement standards for digital networks, including metrics and objectives for network availability, transmission accuracy, connection processing, and synchronization. Working Group T1A1.3 has played a strong role in developing American National Standards and contributing to ITU-T Recommendations on the performance of packet data networks and ISDNs. The work has resulted in development and approval of key ITU-T Recommendations in the X.130 and I.350-series and compatible American National Standards in the T1.500-series. Technical Subcommittee T1A1 has responsibility for standards development in performance and signal processing for emerging broadband networks and multimedia services. Subcommittee T1S1 has played a dominant role in development of national standards and U.S. contributions to ITU-T Recommendations on services, architecture, and signaling protocols for Narrowband and Broadband ISDNs.

The Institute's contributions to ITU-T Study Group 13 played a significant role in advancing several B-ISDN performance Recommendations. During FY 94, Institute contributions provided a framework for addressing technical issues associated with the specification and measurement of B-ISDN call processing and availability performance (draft ITU-T Recommendations I.BCP, I.35X, and I.35BA). The Institute also contributed to the refinement of Recommendation I.356, which defines performance parameters and measurement methods for ATM cell transfer in B-ISDNs. These Recommendations provide a foundation for the deployment of commercial ATM-based multimedia services.

A particular focus of the Institute's international standards work in FY 94 was the specification of performance in public frame relay networks. ITS staff contributed to the development of a new American National Standard, T1.513, that specifies frame transfer performance parameters. Institute staff also contributed to development of a compatible international standard, X.144, that has been approved in ITU-T Study Group 7. These compatible standards are intended to be used: 1) by service providers in planning, developing, and assessing frame relay services that meet user performance needs; 2) by equipment manufacturers as performance metrics that will affect equipment design; and 3) by users as common metrics in evaluating performance of competitive service offerings. The accompanying Figure identifies the set of distinct frame transfer outcomes used in defining the T1.513/X.144 parameters.

Frame relay is designed to provide simultaneous virtual connections through efficient sharing of network resources. Frame relay performance is characterized with reference to negotiated values for traffic parameters to which users are expected to conform (e.g., Committed Information Rate). Institute staff contributed strongly to the definition of a novel test (the double dangerous bridge; DDB), and a new performance parameter (the frame-based conformant traffic distortion ratio; FCTDR) that provide a basis for distinguishing conformant from nonconformant frame relay traffic. The DDB test was selected for use in performance description because it is believed to be more stringent than any reasonable network implementation of conformance testing in traffic enforcement.

ITS members play a significant role in achieving synergy between related national- and international-standards development efforts and compatibility among the evolving national and international standards. Institute leadership and coordination contributed to the achievement of full technical



Frame Transfer Outcomes Used to Define T1.513/X.144 Parameters.

compatibility between ITU-T Recommendation I.356 and its ANSI counterpart, T1.511. Institute staff members spearheaded the development of proposed American National Standard T1.5I, which specifies performance parameters and numerical performance objectives for narrowband ISDN services. This standard is being developed to achieve technical compatibility with the corresponding ITU-T Recommendations I.352-I.355, to which ITS also contributed.

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OBJECTIVE AUDIO QUALITY RESEARCH AND STANDARDS DEVELOPMENT

OUTPUTS

- Objective audio quality assessment algorithms.
- Prototype audio quality test instruments.
- Contributions to standards organizations.

The continued widespread deployment of digital audio encoding, compression, and transmission technology has placed increased importance on the assessment of received audio quality. Due to the wide variety of digital audio techniques and applications, audio quality assessment has become a complex issue. Existing and proposed systems for transmitting audio over digital networks include: 4-kHz speech only systems with bit rates of 2.4 through 64 kbit/s, 7 kHz voice systems with bit rates between 16 and 64 kbit/s, and 15- to 20-kHz multichannel audio systems using bit rates of approximately 128 kbit/s per channel. The bitstreams for these systems may be carried by radio, wire, or fiber and may be multiplexed with video and data bitstreams to provide multimedia communications through Integrated Services Digital Networks (ISDNs). Given the interactions between audio signals, source coding, channel coding, and channel conditions, it is not surprising that the speech transmission quality measurement techniques developed for wired analog telephony fail to provide an adequate characterization of current digital audio systems.

In light of this proliferation of new communications technology, an accurate and reliable way to assess the audio transmission quality of proposed and existing systems and services is essential. The most fundamental and "correct" measures of audio transmission quality are the subjective responses of listeners to audio delivered by the system under test. Since subjective tests are both costly and time-consuming, ITS is developing practical alternatives: objective digital signal processing algorithms that quantify audio performance of a system under test as perceived by the user.

Historically, telecommunications networks have been used primarily for the transmission of speech signals. Therefore, the focus of the objective audio quality assessment algorithms has been on speech signals with a nominal 4-kHz bandwidth. In previous years, the Institute developed an algorithm that uses a 5-point mean opinion score scale to provide indications of speech communication. This algorithm has been applied to 64 kbit/s pulse code modulation, 32 kbit/s adaptive differential pulse code modulation, and 16 kbit/s code excited linear prediction speech communication systems. In FY 94, efforts were focused on developing a perception-based approach intended to extend the scope of objective audio assessment algorithms to include wideband voice, general audio, and more general coding and transmission schemes.

A high-level description of the ITS perception-based approach to objective audio quality assessment is shown in Figure 1. This work centers on careful modeling of human hearing processes along with attention to the higher-level processes of perception and discrimination. Hearing models and test results available in the literature are examined, compared and incorporated when appropriate. As indicated by the

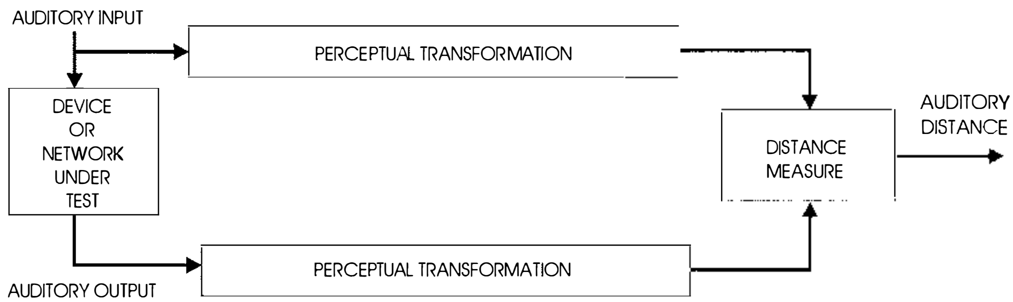

Figure 1. Block Diagram of Perception-based Approach.

diagram, the approach requires access to the input and output of the audio device or network being evaluated. The perceptual transformation blocks are intended to transform these input and output signals in a way that is consistent with human auditory processing.

Key elements of the perceptual transformation model are frequency dependent sensitivity, limited frequency resolution, limited temporal resolution, and nonlinear transfer characteristics of the human auditory system. A bank of nonuniform, overlapping, bandpass filters provides one model for frequency dependent sensitivity and limited frequency resolution characteristics. The response of a proposed filter bank is shown in Figure 2. The filter widths are consistent with the fact that one's ability to resolve neighboring frequencies is nearly constant below 500 Hz, and decreases markedly for frequencies above that point. This effect is attributed to mechanisms inside the cochlea of the ear. Each filter also receives an overall weight so that its peak response is consistent with hearing sensitivity at its center frequency. This sensitivity characteristic can be traced to the acoustic transmission properties of the outer and middle ear. If the energy of an audio signal passing through each of these filters is accumulated over an appropriate time interval, the resulting set of values can be further transformed to generate a mathematical representation for the sensation caused by that audio signal. In general, the necessary transformations are neither linear nor time-invariant.

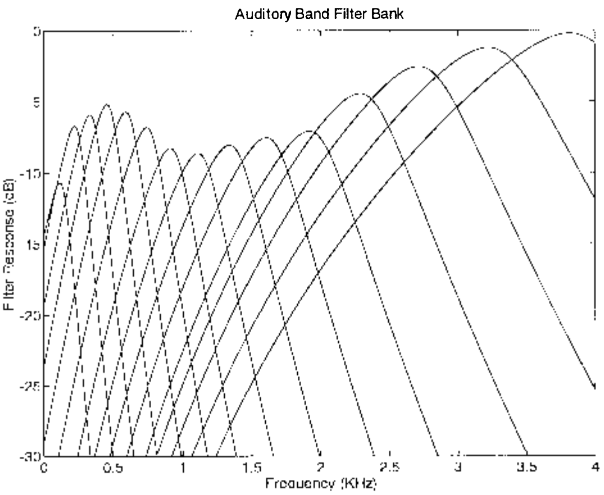

Figure 2. Response of an Auditory Filter Bank.

The distance measure provides a comparison of the two perceptually transformed audio signals and is intended to mimic the judgements that humans make when they compare two audio signals. Since the links between judgement and the underlying physiological processes are not well-understood, the internal details of the distance measure will not correspond to any physiological processes. It is hoped that experimental results can be used to build a distance measure that has the appropriate input-output characteristics. After some additional processing, an auditory distance value would then be generated. This value could be mapped to a user-oriented scale such as the five-point mean opinion score scale.

A simplified algorithm that follows the approach described above has been implemented and initial results look promising. Development and optimization of the full algorithm is the next step. The effort required is significant, but the potential rewards are objective audio quality assessments with wide ranging applicability that can be correlated to subjective audio quality as perceived by users.

Throughout FY 94, the Institute continued its participation in the ANSI-accredited standards working group, T1A1.7. In the International Telecommunication Union-Telecommunication Standardization Sector, the Institute has continued its leadership role as the associate rapporteur for Question 13/12. This question addresses methods of modeling and measuring nonlinear distortion processes in voice transmission. The Institute also participates in the Federal Telecommunications Standards Committee and chairs its Multimedia Telecommunication Performance Measurements Subcommittee.

In addition to standardization activities, ITS objective audio quality assessment technology is transferred by direct demonstration using prototype audio quality test instruments. These test instruments are designed and constructed by ITS staff. They are based on portable personal computers, supplemented with analog conversion hardware. Custom software controls the analog interfaces and executes objective audio quality assessment algorithms. The prototype test instruments have been used to bench test equipment, and to measure speech transmission quality over local telephone loops and long-distance connections. These instruments may lead to development of commercial products that would allow field technicians to use the Institute's objective audio quality assessment algorithms.

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VIDEO QUALITY STANDARDS DEVELOPMENT

OUTPUTS

- Automated digital video quality measurement techniques and prototype instrumentation.
- Contributions to national and international standards committees.
- Technical input to development of U.S. policies on advanced video technologies.

Digital video compression, storage, and transmission systems are essential components of the National Information Infrastructure (NII). These systems introduce fundamentally different impairments than those created by traditional waveform reproduction methods. Examples of compression-related impairments in video communications are error blocks, localized image smearing, and jerky motion. For digital video systems, the information content of the source video signal plays a crucial role in determining the amount of compression that is possible and the severity of compression artifacts. Thus, the user-perceived quality of a digital video transmission system is a dynamic function of both the system and the input signal. The urgent need for performance measurements that correlate with the perception of digital video transmission quality has led ITS to seek new video quality measures that are objective and perception-based. Such measures are chosen on the basis of their correlation with the subjective video quality assessments of human users. They are derived from the electrical and mathematical properties of the digitized input and output signals, and are implementable in automated test equipment. They achieve technology independence by recognizing important perceptual attributes and subsequently predicting human reactions to imperfections in received visual information.

The facing Figure presents a block diagram of a video quality measurement system that was developed by ITS. The measurement system is composed of two subsystems: a source instrument and a destination instrument. The source instrument attaches nonintrusively to the source video and extracts a set of source features that can be used as a reference to quantify perceptual video quality changes. The destination instrument attaches nonintrusively to the destination video and extracts an identical set of destination features. Objective quality parameters can then be obtained by comparing the source features with the corresponding destination features. Two kinds of features have proven to be most useful for measuring video quality. One measures spatial distortions in the video (e.g., blurring) and the other measures temporal distortions in the video (e.g., jerky motion). Designers of modern video transmission systems often trade spatial and temporal performance aspects, and some have even made these trade-offs selectable. Perception-based video quality features can be represented by only a few bits and can thus be transferred between the source and destination locations easily and economically. If a transmission system is used for interactive communications, then video delay is another important quality attribute of the transmission system. Video delay can be computed by the ITS measurement system via a time alignment correlation process applied to temporal features.

Objective parameters can be combined to produce a composite estimate of what the viewer response would be to the perceived video quality. Experiments have demonstrated excellent correlations between composite objective estimates and subjective test data. These results are technology-independent in that they are applicable to an extremely wide range of video systems, including very high quality 45 Mb/s studio NTSC systems. ITS continues to transfer this promising video quality measurement technology into the private sector and the appropriate standards bodies, such as ANSI- accredited Telecommunications Working Group T1A1.5 and International Telecommunication Union-Telecommunication Standardization Sector Study Group 12.

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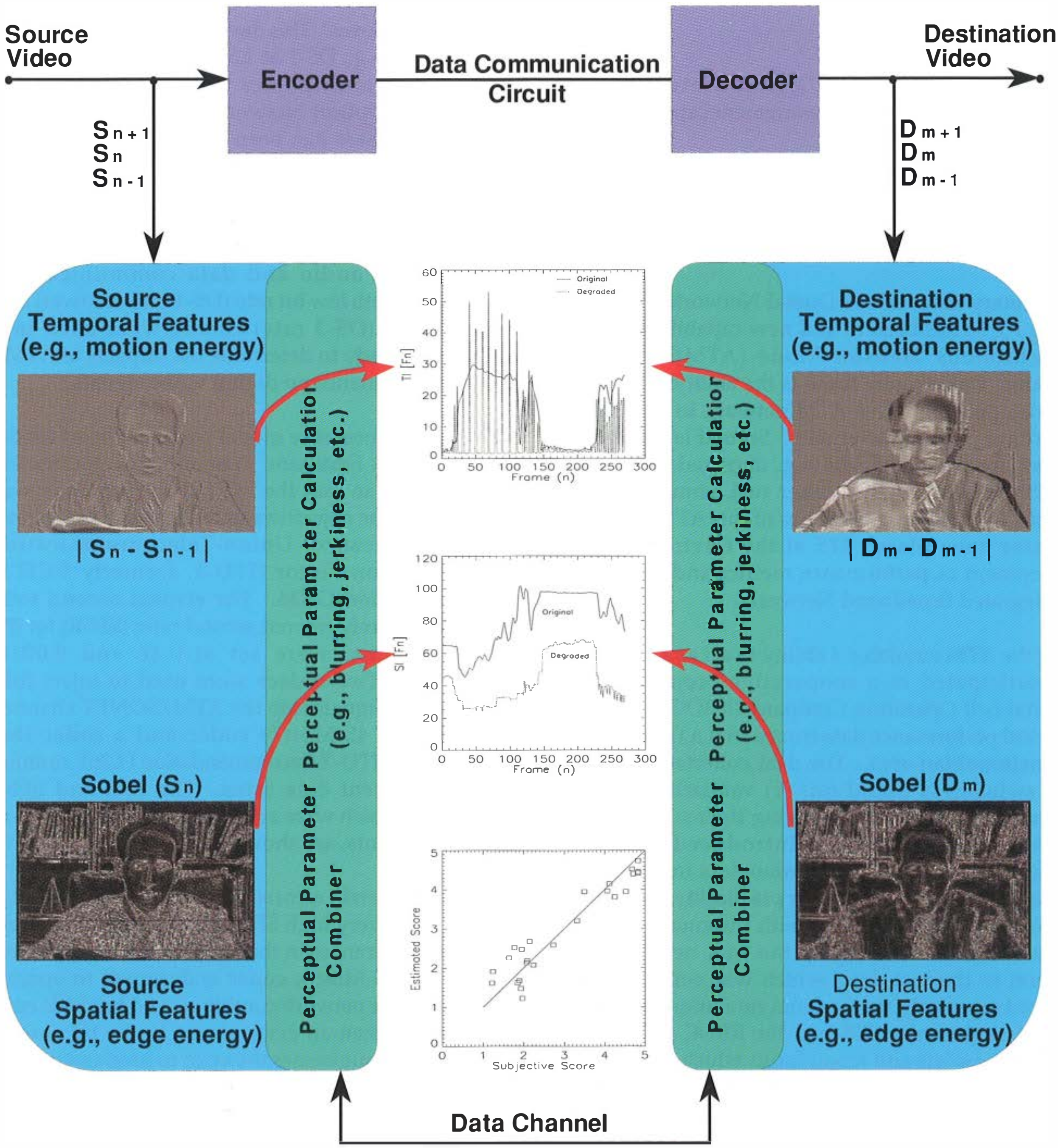

The ITS Video Quality Measurement System.

DIGITAL NETWORKS PROGRAM

OUTPUTS

- Integrated Services Digital Network and broadband network measurement capabilities.
- Performance measurement software and results.
- Standard performance parameters and measurement methods.

The primary focus of the Digital Networks Program during FY 94 has been to add new capabilities to the Asynchronous Transfer Mode (ATM) Network Emulator. First among these is the ability to act as a terminal, probing a live ATM network to determine its performance characteristics. Second is the ability to inject streams of live data (e.g., digitized video) into an ATM network that is either real, emulated, or a hybrid. The unique capabilities of this ATM network emulator have placed ITS at the forefront in the development of performance metrics and standards for Integrated Broadband Networks.

Using the ATM emulator's ability to act as a terminal, ITS participated in a cooperative project with a Regional Bell Operating Company (RBOC) to gather empirical performance data from a trial ATM network in a metropolitan area. The data collected from the ATM switches is useful for: 1) validating the ITS network emulator and improving the realism of the controlled impairments introduced therein; 2) validating performance parameters in emerging standards, including parameter practicality and utility, and 3) providing the RBOC with information about utilization and efficiency of the trial network. In addition to the test data, which was collected and analyzed separately, the terminal emulation capability allowed engineers at ITS and the RBOC to work in real time to isolate and repair faults which occurred in the trial network. Tests performed on the trial network provided a 24-hour utilization profile and information on cell transfer delay, cell delay variation, and cell loss.

While the terminal emulation capability was achieved through the use of software, the ability to impair streams of live data required additional hardware. The centerpiece of this capability is a device called a "service multiplexer." This device takes plesiochronous data streams (e.g., DS-1 at 1.5 Mbit/s and DS-3 at 45 Mbit/s) and multiplexes them onto an ATM/ Synchronous Optical Network (SONET). The ATM network emulator has been designed to accept an ATM/SONET data stream as an input.

Sources that generate DS-1 or DS-3 data streams are widely available and include video coder/decoders (codecs) with audio and data communications capabilities. Both low bit rate (DS-1 rate or lower) and high bit rate (DS-3 rate) coders were used in a preliminary study to determine the impacts of ATM/ SONET performance on digital video signals.

In FY 94, a performance model was developed for the ATM Network Emulator. The model's parameters were adjusted so that the SONET performance was equivalent to the objectives stated in the International Telecommunication Union-Telecommunication Standardization Sector (ITU-T, formerly CCITT) Recommendation G.826. The errored second ratio (ESR) and severely errored second ratio (SESR) for the SONET channel were set at 0.16 and 0.0018, respectively. Two codecs were used to inject full-motion video signals into the ATM/SONET channel. These were a 45 Mbit/s codec and a codec that complied with ITU-T Recommendation H.261 running at three different data rates. The ESR and SESR parameters, which were measured from recordings of the codec outputs, are shown in the Table.

The lack of severely errored seconds for the 45 Mbit/s codec and the very high SESR for the H.261 codec are a result of differences in the way the two coders treat errors. The 45 Mbit/s codec is designed to operate under error free network conditions and has little error protection. When an error occurs in the bit stream, the coding scheme causes the error to propagate down and to the right in the video image; ultimately it propagates into the synchronization pulses and the rest of the frame becomes "confetti" noise. This is graphically demonstrated in Figure 2, which can be compared to the source video image in Figure 1. The error is not propagated between frames, however, and the video returns to normal on the next frame (barring any additional bit errors). This appears as a flash to a viewer, but is not perceived as a service outage of any sort. The H.261 codec, on the other hand, has some error protection, but when the errors become too severe, the video can "freeze." These freezes can last anywhere from a second to over a minute, with the average time decreasing as the video bit rate decreases. Once the freeze is over, the codec requires from one to thirty seconds for its output video to regain a correct relationship to the input video. This recovery is shown in process in Figure 3. The tendency for the H.261 codec to take many seconds to recover from the severe error event results in a multiplicative effect on a measure such as SESR.

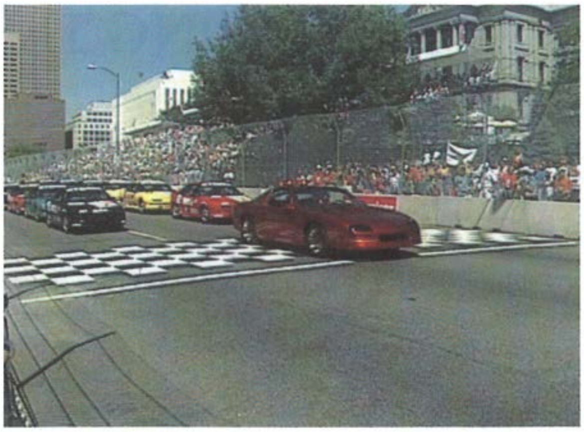

Figure 1. Source Video.

Codec performance with SONET/OC-3
ESR = 0.16 and SESR = 0.0018

CIRCUIT	ESR	SESR
45 Mbit/s video	123	0
1.5 Mbit/s video	.090	.066
384 kbit/s video	.026	.0088
128 kbit/s video	.014	.0041

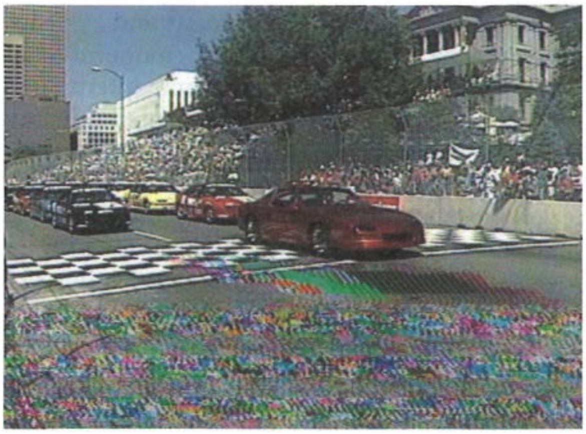

Figure 2. Video Degraded by Error in the 45 Mbit/s Data Stream.

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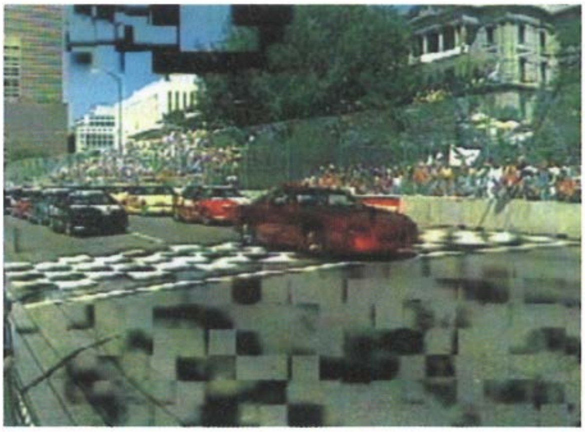

Figure 3. Video Degraded by Error in the 1.5 Mbit/s Data Stream.

TELECOMMUNICATION AND INFORMATION-PROCESSING TERMINOLOGY STANDARDS

OUTPUTS

- U.S. contributions to ISO-2382, *Information Technology—Vocabulary.*
- Support of ANSI-accredited Technical Committee X3K5 in development of the *American National Standard Dictionary for Information Systems.*
- Support of the FTSC Subcommittee to revise Federal Standard 1037B, *Glossary of Telecommunication Terms.*

Compatibility among telecommunications and information-processing equipment and systems is a critical issue in promoting U.S. competitiveness in world trade. ITS programs promote interoperability and commonality among such systems in several ways. Among these are contributions to telecommunication and information system terminology standardization. Telecommunication and information system glossaries, developed under ITS leadership, improve collective understanding of basic concepts within the telecommunication and information industries and contribute to clarity and precision in the specification of user requirements and product capabilities.

Recent developments in open data networks, electronic mail (e-mail), National Information Infrastructure (NII), and other communications technologies have spurred efforts to develop a common vocabulary for these concepts. Standardized definitions of telecommunications terminology are being developed at the international, national, and Federal levels as shown in the Table. Under the sponsorship of the National Communications System (NCS), ITS participates in vocabulary standardization work at each of these levels. Each glossary project involves the development and coordination of a large telecommunications dictionary containing terminology relevant to both general industry needs and specific NCS and NTIA responsibilities for National Security/Emergency Preparedness and development of the NII.

In its international terminology standardization work, ITS serves as convener of the International Organization for Standardization (ISO)/International Electrotechnical Commission (IEC) Working Group 7, *Vocabulary for Data Communications.* During FY 94, the Working Group met twice to develop vocabulary for databases, data communication, and for e-mail. ITS also serves as the project editor for the English text of several subparts of ISO/IEC 2382, *Information Technology—Vocabulary.*

On a national level, ITS serves as Vice Chair of ANSI-accredited Technical Committee X3K5 in developing the *American National Standard Dictionary for Information Systems* (ANSDIS). ITS also serves as project editor for the revision of ANSDIS, which is in final stages in the committee and is expected to be released for review next fiscal year.

In its Federal level work, ITS chairs the Federal Telecommunications Standards Committee (FTSC) Subcommittee to Revise Federal Standard 1037B, *Glossary of Telecommunication Terms.* That subcommittee met for ten 5-day sessions in FY 94 and reviewed more than 4000 proposed revisions to the standard, including more than 120 figures. The format of the meetings allowed the participants to see proposed definitions on computer screens placed for optimum viewing at a conference table. The screens reflected the subcommittee's revisions in real time, as the text was entered into the computer database constituted a draft of the proposed Federal Standard 1037C (pFS-1037C). The revisions from each meeting were made available on the Internet less than a week after each meeting concluded. Therefore, each stage of development of the Coordination Draft of pFS-1037C (except for the figures) has been accessible to all users of Internet throughout the revision process. The Figure depicts the subcommittee in session, preparing the Coordination Draft of pFS-1037C for Governmentwide review in the next fiscal year.

ITS' goal in each of the three areas—international, national, and Federal—is to promote a congruence of definitions so that communication is enhanced for users of all of these related standards.

As a key participant in each of these glossary committees, ITS also can promote congruence between pFS-1037C and other vocabulary standards, such as the *National Information Systems Security Glossary*. The Institute had some unique opportunities to make use of synergies in the glossary projects underway during FY 94. The benefits of common vocabulary at all three levels reach beyond the vocabulary committees and into the designers' workshops, the purchaser's desks, and into the telecommunications marketplace, worldwide.

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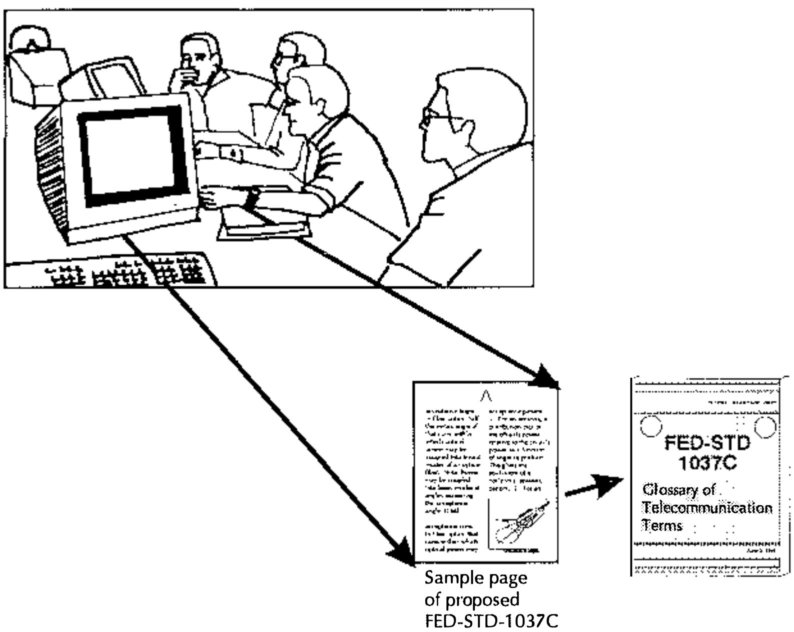
Levels of Terminology Development

Level	Organization	Product
International	ISO/IEC Working Group 7, *et al.*	Information Technology-Vocabulary (ISO/IEC-2382)
National	ANSI, *et al.*	American National Standard Dictionary for Information Systems (ANSDIS)
Federal	NCS, GSA, FTSC, *et al.*	Glossary of Telecommunication Terms (pFED-STD-1037C)



Proposed Federal Standard 1037C Process.

PERSONAL COMMUNICATION SERVICES STANDARDS SUPPORT

OUTPUTS

- Support to the Joint Technical Committee on Wireless Access.
- Independent observation of common air interface field trials.

Personal communication services (PCS) is the name given to the next generation of digital mobile telephone service within North America. PCS employs state-of-the-art digital communications technology to provide an array of user services including near landline voice quality, medium to low rate data transfer, personal and terminal mobility, user profile management, and seamless nationwide roaming. As a result of the high-quality service, the anticipated low cost, and the wide coverage area, PCS is expected to become a multibillion dollar industry within a few years. The key to the success of PCS is the development of open industry standards.

Air interface standards for North American PCS are being developed by the Joint Technical Committee on Wireless Access (JTC). The JTC is a cooperative effort between the ANSI-accredited Committee T1 T1P1 and the Telecommunications Industry Association (TIA) TR46.

During the past year, ITS has lead in three critical areas within the JTC: RF channel characterization, system deployment modeling, and development of the technology field trials test plan. ITS personnel chaired the respective ad hoc groups in which these activities took place, authored and edited the "Final Report on RF Channel Characterization and System Deployment Modeling," and authored the original version of the technology field trials comprehensive test plan.

The JTC has established a criterion by which the candidate air interfaces can be forwarded for ballot to T1P1 as a Standard or a Technical Report (TR) and to TR46 as an Industry Standard or Technical Service Bulletin (TSB). To be forwarded as a TR or TSB, the proponent must complete a system characterization document as well as an extensive system deployment model. To be forwarded as a standard, the proponent must also sign a letter of agreement that they will submit their system to technology field trials within six months of forwarding for ballot. The radio characterization report, the model system deployment, and the technology field trials are designed to demonstrate the performance of the air interface.

The JTC is using the US West Technologies' Boulder Industry Test Bed (BITB) as a common location for the technology field trials. ITS, through a cooperative research and development agreement, is affiliated with the test bed and is providing part of the test bed infrastructure.

As a result of its knowledge of the candidate systems, understanding of the standards process, and technical neutrality, ITS was asked by the JTC to act as an independent observer of the technology field trials. In this role ITS personnel observe and assist with the conduct of the trials and verify the accuracy of the results.

In November of 1993 seventeen common air interface proposals were presented to the JTC. Through a process of consolidation, the number of candidate air interfaces has been reduced to seven. Following is a brief description of each proposed air interface.

- **IS 95-based CDMA.** Code division multiple access (CDMA) is a spread spectrum system that allows users to access cells based on a unique pseudorandom code and provides for noise mitigation. This proposal is based on the existing TIA Interim Standard (IS) 95 which has a 1.25-MHz spreading bandwidth.
- **Composite CDMA/TDMA.** This interface employs time division multiple access (TDMA) for user access within a cell and spread spectrum techniques for orthogonality between adjacent cells and noise mitigation.
- **DCS-based TDMA.** This proposed air interface is a derivative of the European Digital Cellular System (DCS) 1800, itself a variant of the Global System for Mobile communications. It is an eight-time slot per carrier system employing space diversity and adaptive equalization.

- **IS 54-based TDMA**. This is a variant of the existing TIA Interim Standard 54. It is a six-time slot per carrier system employing adaptive equalization. In its current configuration, two time slots are required per user. A half rate coder/ decoder that will require only one slot per user is anticipated.

- **DECT-based TDMA.** This common interface is a derivative of the Digital European Cordless Telephone (DECT) standard. Designed for low mobility applications, it employs a twelve-time slot per carrier TDMA system.

- **Wideband CDMA.** This has a 5-MHz spreading bandwidth which allows for a higher rate speech coder/decoder and higher rate data services.

- **PACS TDMA**. Personal Access Communication System (PACS) is an eight-time slot per carrier TDMA system based on the Wireless Access Communication System specified by Bellcore. It is intended for low mobility, small cell deployments.

ITS continues to support the PCS standards process by providing technical inputs from the many mobile propagation experiments conducted through cooperative research and development agreements with private industry (see the photograph). ITS is also currently developing simulations of the various candidate air interfaces which include both propagation models developed for the JTC and actual measured channel impulse response data. This will help ensure that the ballot standards meet the needs of the Government and private service providers and users in all the necessary operating environments. As PCS deployment nears reality, ITS is working on developing system deployment tools such as spectrum sharing models and environment specific propagation tools. For support of worldwide export of U.S. PCS technology, ITS has made available international terrain databases for use with the coverage prediction tools on its Telecommunications Analysis Services system.

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Antenna of a PCS System Under Test on Enchanted Mesa West of the Department of Commerce Boulder Labs (visible at the lower right). *Photograph by F Sanders.*

WIRELESS LOCAL AREA NETWORK STANDARDS SUPPORT

OUTPUTS

- Indoor channel measurements.
- Geometric optics indoor channel model.
- Performance prediction of WLAN system using a realistic indoor channel.

Wireless Local Area Network (WLAN) devices are expected to be ubiquitous in the near future. The idea of WLAN connectivity was attractive initially to organizations that frequently moved personal computers or point-of-sale terminals. Now, with the advent of laptop computers and personal digital assistants, mobile personal computing is a reality and consumers are demanding high-speed WLAN connectivity.

High-speed WLAN performance is limited by the radio channel. The channel, whether indoors or outdoors, is dominated by the effects of shadowing, multipath, and cochannel interference. Shadowing decreases the radio coverage of a transmitter. Increased effective isotropic radiated power (EIRP), or shorter link distances are necessary to overcome shadowing. Multipath causes power fading in narrowband radios and intersymbol interference in wideband radios. Methods such as spread spectrum modulation, antenna diversity, and channel equalization are used to mitigate the effects of multipath. WLANs currently do not have their own frequency allocation and must work in the presence of cochannel interferers. Strategies fo spectrum etiquette are needed to allow all users fair access to the shared spectrum. ITS is committed to solving these problems by working with the Institute of Electrical and Electronics Engineers (IEEE) 802.11 WLAN standards group, conducting radio channel measurement campaigns, modeling the radio channel, and performing radio system simulations with realistic radio channels.

At ITS, indoor channel multipath is measured with a wideband channel probe. The channel probe uses the pseudorandom noise sliding correlator technique, which provides excellent dynamic range for the impulse response measurements. The ITS probe is unique in the industry, in that it provides impulse response measurement bandwidths from 200-1000 MHz. These bandwidths provide excellent time delay resolution of the channel.

ITS completed an initial set of indoor radio channel measurements of a hallway, an auditorium, and an open soft-partitioned office space. The office measurements were accepted by the IEEE 802.11 to be the standard channel used for simulations submitted to the working group. ITS has made additional measurements in a warehouse environment at 5.8 GHz using directional antennas. The data is currently being analyzed to determine how well directional antennas mitigate multipath distortion.

ITS has recently proposed a geometric optics channel model to the IEEE 802.11. The model generates a set of impulse responses experienced by a radio as it is moved along a path through a room. Key features of the model include :

- the room wall, floor, and ceiling materials are modeled with realistic dielectric properties,
- reflection coefficients vary with polarization and angle of incidence, and
- the transmitter and receiver can have any three-dimensional antenna pattern.

In FY 94, ITS has successfully incorporated modeled and measured impulse responses in WLAN system performance prediction using a commercial off-the-shelf communications simulation tool. Engineers at ITS have written a module for this tool that allows the impulse responses to be used as the radio channel during the simulation. Figure 1 shows a WLAN radio link being distorted by measured impulse responses and interfered with by a cochannel interferer. Results of this simulation are summarized in Figure 2. Each curve in the plot shows how bit error rate (BER) varies with signal-to-noise ratio (SNR) for a fixed carrier-to-interference ratio (CIR).

WLAN simulations at ITS have focused on waveform distortion in the radio link. This level of simulation is relevant when studying the radio channel's effect on various modulations. Once the modulation has been standardized, however, network simulation using discrete channel models will play a more important role. In FY 94 ITS successfully built a discrete channel model of the indoor channel based on results from its waveform simulation efforts.

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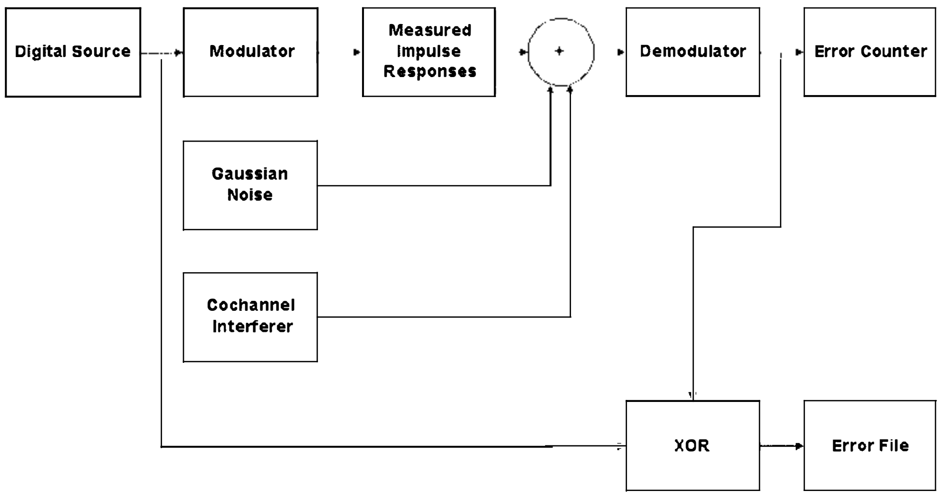

Figure 1. WLAN Simulation Block Diagram.

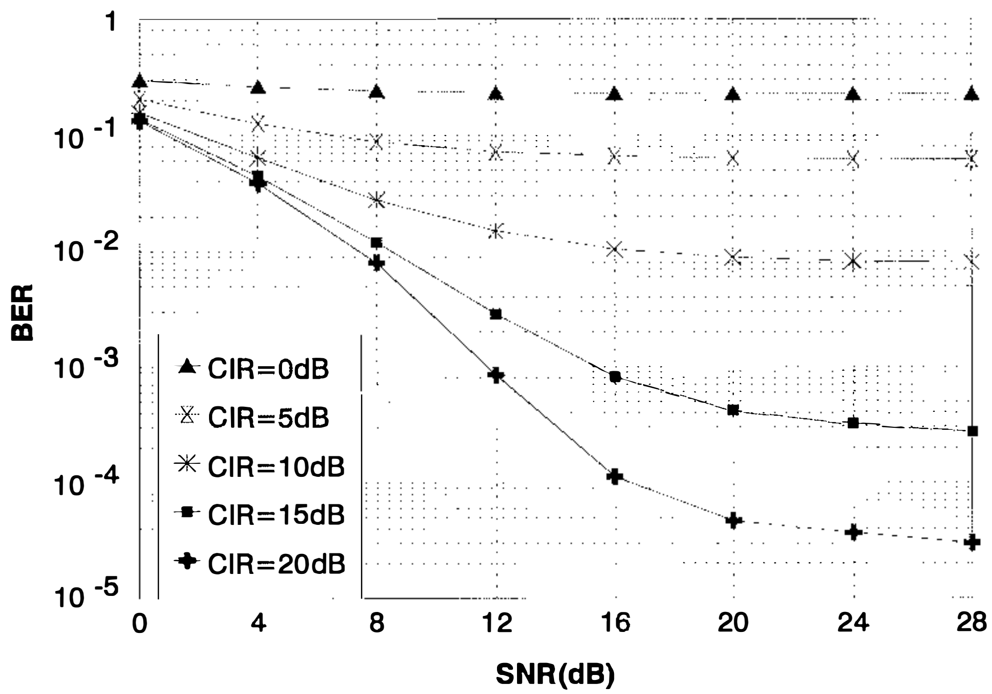

Figure 2. WLAN Simulation Results.

TELECOMMUNICATIONS TRANSMISSION MEDIA TECHNOLOGY STUDIES

OUTPUTS

- ANSI/TIA/EIA telecommunication standards for premises cabling, optical fibers, optical fiber cabling, and grounding and bonding.
- Federal standards and Federal information-processing standards that adopt the technical content of these industry standards.

The Federal Telecommunication Standards Committee (FTSC), chaired by the National Communications System (NCS), is responsible for establishing Federal standards to promote the interoperability and survivability of telecommunications systems owned or leased by the Federal Government. ITS staff supports the FTSC in fulfilling this responsibility by contributing to industry standards organizations when Federal and industry standards objectives coincide. A key consideration of NCS and ITS is participation in the development of standards that advance National Information Infrastructure (NII) objectives.

During FY 94, the Institute's contributions to transmission media standardization were focused on two committees within the Telecommunications Industry Association (TIA): TIA TR-41 on *User Premises Telecom Requirements* and TIA FO-6 on *Fiber Optics*. During development of a standard, the Government's telecommunications concerns are presented and addressed. Institute staff members coordinate a standards review and comment process throughout the Federal Government in parallel with industry balloting (in ANSI and TIA) of the standard. The Institute also presents the Government's comments to the TIA committees. Upon publication of the industry standard, the FTSC adopts the standard for use by Government agencies in the form of a Federal Information Processing Standard (FIPS PUB).

During 1994, ITS was involved in the ongoing development of the family of standards that collectively specify a local telecommunications infrastructure. These standards address wiring and cabling components in support of a structured wiring system for premises and campus environments, architecture to support space and pathways for cabling and equipment, architecture for telecommunications bonding and grounding, and administration of the telecommunications facilities. The Table below lists the industry standards and the equivalent Federal standards that make up the family. The scope of the infrastructure standards is depicted in the Figure.

Following is a brief summary of the 1994 achievements and activities of Institute staff in the telecommunications infrastructure standards.

- **ANSI/TIA/EIA-568-1991–Commercial Building Telecommunications Cabling Standard**. This standard, currently under revision, is anticipated for publication as ANSI/TIA/EIA 568-A during the 1995 calendar year. The Institute participated in formulating the revised standard, coordinated the review and comment process within

Family of Telecommunications Infrastructure Standards

ANSI/TIA/EIA Standard	Status	FIPS Publication
ANSI/TIA/EIA-568-1991	Under revision	FIPS PUB 174
ANSI/TIA/EIA-569-1990	Under revision	FIPS PUB 175
ANSI/TIA/EIA-570-1991	Under revision	FIPS PUB 176
ANSI/TIA/EIA-606-1993	--	FIPS PUB 187
ANSI/TIA/EIA-607-1994	Under revision	To be determined

Government for three balloted drafts, and represented the Government's interests before the industry working group.

- **ANSI/TIA/EIA-606-1993–Administration Standard for the Telecommunications Infrastructure of Commercial Buildings**. ITS coordinated the review and comment process within Government for the balloted industry draft, and presented more than one hundred Government comments to the industry working group. The Institute prepared the final draft for publication of the standard as FIPS PUB 187.

- **ANSI/TIA/EIA-607-1994–Commercial Building Bonding and Grounding Requirements for Telecommunications**. The Institute staff served as secretariat of the working group developing the standard. During FY 94 the Institute advanced the Government review process for two industry ballots of the standard. The Institute is currently assisting in preparing the final draft for publication as a FIPS PUB.

ITS participated in the newly formed TIA Subcommittee on Multimedia Building Distribution Systems (TR-41.5). ITS serves as secretariat of this Subcommittee whose objective is to provide recommendations (in the form of standards) on system architecture configurations required to support multimedia services on the customer premises. Much effort has been directed to establishing liaisons with other standards bodies and Government agencies to take advantage of existing standards which may satisfy system architecture concerns and promote the objectives of the NII.

With ITS technical support, the Fiber Optics Division of TIA has accomplished major revisions of the entire Series 492 hierarchy of optical fiber specifications, including detail specifications targeted toward procurement. In two cycles of preliminary review at the FO-6 Subcommittee level, the detailed specification received substantive technical comments from a broad cross-section of industry and Government. The formal industrywide Standard Proposal review is in process, with subsequent adoption of the detail specifications as a FIPS PUB anticipated.

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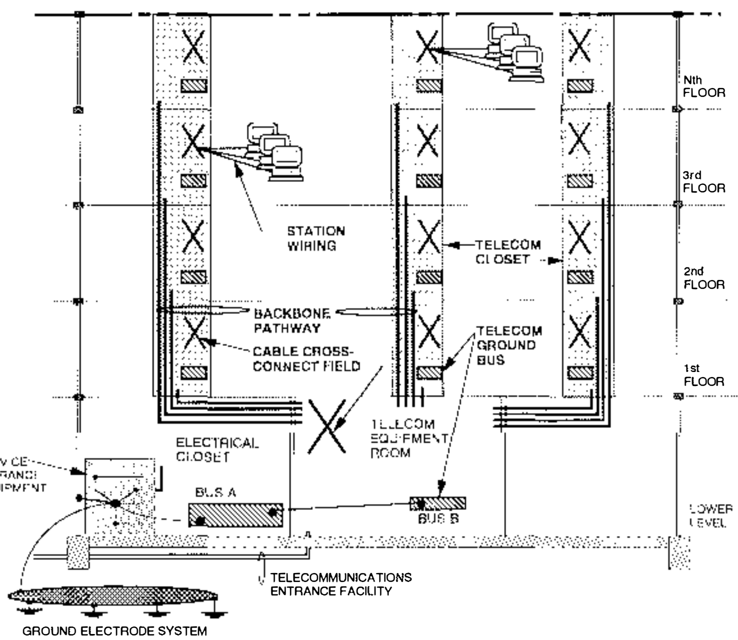

Telecommunications Infrastructure.

Global Positioning System Satellite. **See Augmented Global Positioning System, Page 48.**
Graphic Courtesy of Martin Marietta.

TELECOMMUNICATION SYSTEM PLANNING

The planning of telecommunication systems involves different problems with associated solutions for different aspects of system development. For example, a need for telecommunications is identified for a new application, such as the Intelligent Vehicle Highway System. For this case, the planning involves defining the environment in which the system will operate, establishing the types of information to be communicated (i.e., voice, video, images, and data), finding the frequency bands technically and administratively appropriate for the service, and determining the impairments that the system will need to overcome. With these conditions established, the system designers can develop the telecommunication system. Another example is planning a system in an existing service, such as a new cellular phone service in a community. Such planning can make use of available models to design and develop the system.

The Institute has the resources to assist with all aspects of telecommunication system planning. Those skills allow ITS to determine user requirements, identify appropriate regulations and policies affecting the system, evaluate alternative technologies, and design network architectures and systems.

AREAS OF EMPHASIS:

Intelligent Vehicle Highway System
Includes projects funded by the Federal Highway Administration.

Advanced Systems Planning
Includes projects funded by the USDA Forest Service and the Federal Railroad Administration.

National Information Infrastructure Program Planning
Includes projects funded by NTIA.

Telecommunications Analysis Services
Includes projects funded by the National Weather Service, the Department of Transportation, and public users of the service.

Augmented Global Positioning System
A project funded by Department of Transportation.

Impacts of Foreign Source Dependence on the Telecommunications Infrastructure
Includes projects funded by the U.S. Army Defense Information Systems Agency.

INTELLIGENT VEHICLE HIGHWAY SYSTEM

OUTPUTS

- Characterization of the roadway electromagnetic environment.
- Propagation modeling for the roadway environment.
- Electromagnetic compatibility analysis of the Intelligent Vehicle Highway System and subsystems.
- Support for IVHS committees for communications, spectrum, and electromagnetic compatibility.

The Intelligent Vehicle Highway System (IVHS) is one approach to solving the increasing congestion of roadways in the United States. Traffic congestion causes a loss in productivity, accidents, wasted energy, and increased vehicle emissions. Safety on the nation's highways is also of prime concern. The conventional solution of building more roads will not work in many areas of the country for both financial and environmental reasons.

Recognition of these problems in surface transportation led to the passage of the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991. The purpose of ISTEA is to develop a national intermodal transportation system that is economically efficient, environmentally sound, provides the foundation for the Nation to compete in the global economy, and will move people and goods in an energy-efficient manner.

The surface transportation goals of ISTEA can be met by IVHS. IVHS is a group of functions that includes information processing, navigation, communications, and control. IVHS can improve safety, reduce congestion, enhance mobility, minimize environmental impact, save energy, and promote economic productivity in our transportation system. The highway applications of emerging technologies to support navigation, communications, and vehicle identification and control can contribute to the solution of congestion, safety, and other highway problems.

IVHS utilizes computer and telecommunications technology to provide information to travelers about road and transit travel conditions and to monitor, guide, and control the operation of vehicles. IVHS can enable travelers to make more informed choices about routes, times, and modes of travel. It will also allow authorities to manage transportation systems and control traffic more efficiently. In the future, IVHS will assist drivers and reduce accidents through automation of vehicle control.

IVHS will enable a range of transportation strategies to be implemented more effectively than they are currently. These include: 1) rapid response to road accidents to restore traffic flow, 2) redirecting traffic away from the most congested routes, 3) ridesharing, 4) traffic control at intersections and on street networks, 5) ramp metering on freeways, 6) reserved lanes for buses and high-occupancy vehicles, and 7) toll collection. Some of these measures might be employed only in extreme situations, such as major accidents, disasters, environmental emergencies, or fuel shortages, which have a low probability of occurring but high costs if they do occur.

Electromagnetic compatibility (EMC) is a primary consideration in IVHS design. ITS is addressing the EMC of IVHS by participating in many activities during the initial conception, design, development, and testing phases of IVHS and will follow them through the entire lifecycle of updates and modifications. ITS activities include, but are not limited to: 1) characterization of the electromagnetic environment, 2) spectrum planning, 3) propagation model development, 4) determination of suitable new and emerging communications technologies for IVHS, 5) prediction of radio coverage for communication systems, 6) selection/establishment of an EMC requirement standard for IVHS, 7) creation of an EMC control plan, 8) selection/development of an EMC testing standard for IVHS, and 9) creation of an EMC test plan. ITS is also involved in system architecture evaluation during the concept and design phases and will ensure EMC for demonstration projects during the course of IVHS development.

Areas of EMC consideration include any equipment, subsystem, or system that is part of the IVHS and its intended operational environment. EMC must be considered 1) within the vehicle between different IVHS equipments/subsystems, 2) between IVHS equipments on different vehicles, 3) between vehicles and other elements of the IVHS infrastructure, and 4) between the IVHS and the total environment. "Vehicles" include private vehicles, buses, and commercial freight and transport vehicles such as trucks. The performance of the communication, radar, navigation, and electronic control systems and subsystems are increasingly dependent upon the compatible coexistence of all of these electronic systems.

Recent ITS activities and accomplishments on IVHS include: a radiation hazard bibliography, a published study of emitters in the radio environment, an EMC analysis of the Electronic Toll and Traffic Management System, an assessment of propagation models for use in IVHS with recommendations for future development, and ongoing committee support for the IVHS communications committee.

The Figure is a pictorial representation of IVHS. It illustrates the concepts of vehicle-to-roadside and vehicle-to-vehicle communications, collision avoidance radars on vehicles, automatic vehicle identification for fleet management and toll collection, in-vehicle information and route guidance for navigation, and traffic management center information dissemination and control.

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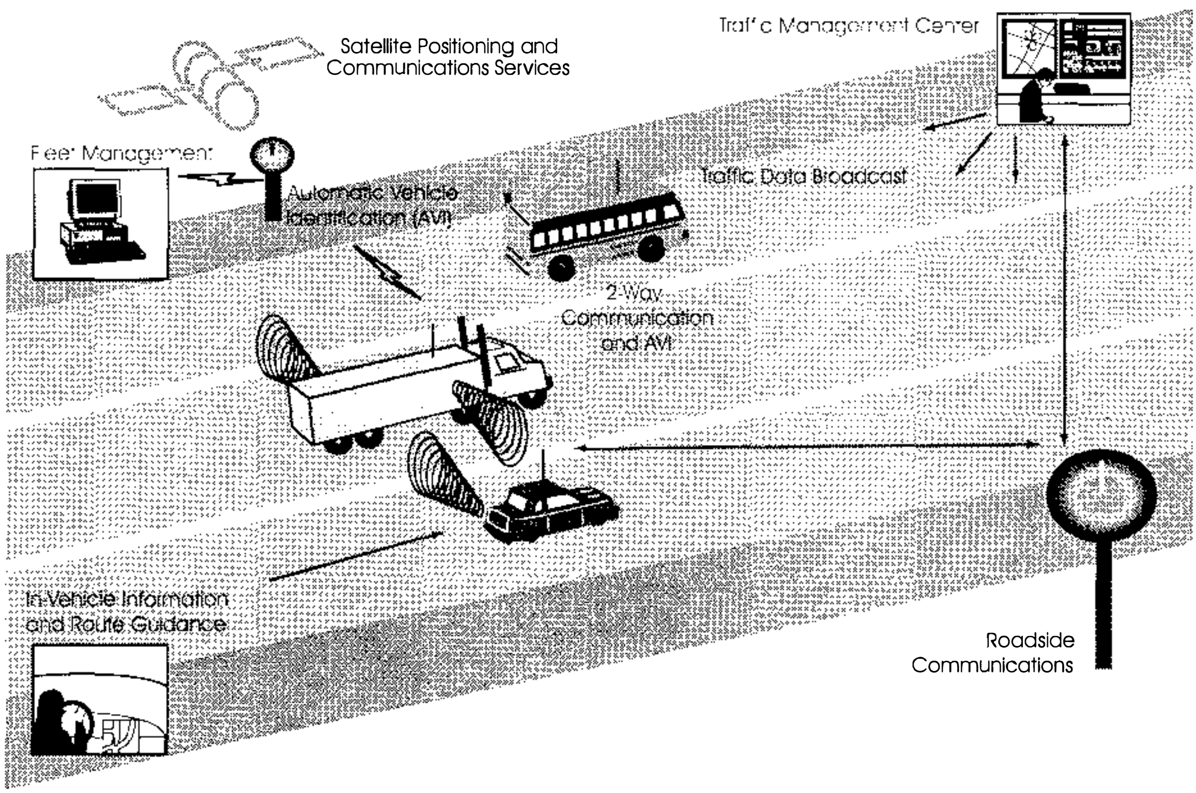

The Intelligent Vehicle Highway System Concept.

ADVANCED SYSTEMS PLANNING

OUTPUTS

- Ten-year strategic telecommunication plan for the Eastern Region of the USDA Forest Service.
- Three-year tactical telecommunication plan for each of the 15 National Forests in the Eastern Region of the USDA Forest Service.
- Evaluation of the industry-proposed Advanced Train Control System for the Office of Safety Enforcement of the Federal Railroad Administration.

Telecommunication system planning is often done on a short-term basis, with little consideration of emerging technologies or evolving organizational needs. Such an ad hoc approach can maintain essential capabilities, but often does not use telecommunications effectively in meeting the business goals of the organization. ITS provides advanced systems planning services to assist user organizations in analyzing their telecommunications needs and selecting systems that will meet those needs within budget and policy constraints. ITS also evaluates proposed telecommunication systems with respect to development, feasibility, appropriateness, and implementation.

USDA FOREST SERVICE TELECOMMUNICATION PLANNING

The Eastern Region of the U.S. Department of Agriculture (USDA) Forest Service tasked ITS to develop an Eastern Region Strategic Telecommunications Plan, and a Tactical Telecommunication Plan for each of the Region's 15 national forests. The Strategic Plan and the forest tactical plans work in tandem to help ensure that the USDA Forest Service telecommunication systems and services support the mission of the organization in a reliable and cost-effective manner.

The Strategic Plan addresses the 10-year period from 1994 through 2003, and is intended to provide overall guidance in telecommunications planning and implementation for the National Forests in the Eastern Region. It identifies telecommunications needs and establishes goals for the future of USDA Forest Service telecommunications. The Strategic Plan incorporates an assessment of existing telecommunication systems, and also assesses internal and external constraints that affect how a Region can move from existing capabilities toward its telecommunications goals. Current and evolving telecommunications technologies are also assessed. The plan defines a comprehensive long-range strategy that accounts for the factors mentioned above, and a regional strategy that provides the framework for decision-making at the Forest level. The Regional telecommunications strategy has six components:

- Ensure that telecommunications management responsibilities are adequately defined and effectively achieved at the Region and Forest levels.
- Accommodate the diverse technical capabilities of USDA Forest Service telecommunication system users.
- Establish Forest-level accounting and funding mechanisms that provide cost-effective management and timely procurement of telecommunication systems and services.
- Pursue telecommunications cooperation with other agencies, commercial interests, academia, and the general public.
- Migrate toward high-speed, integrated, digital networks capable of supporting the transmission of voice, text, graphics, and video information; migrate toward open, standards-based systems and interfaces.
- Restore existing telecommunication systems to designed operating parameters; address immediate system shortcomings.

The Forest tactical plans address the period from 1994 to 1996. They are unique to each Forest and identify specific steps to implement the regional strategy. The tactical plans address telecommunications management issues and include product recommendations and estimated costs for equipment repair and/or replacement.

SYSTEM EVALUATION FOR THE FEDERAL RAILROAD ADMINISTRATION

The Association of American Railroads and the Railways Association of Canada have proposed a set of specifications for the North American Advanced Train Control System (ATCS). The ATCS is a communications-based system that transmits command and control information between dispatch centers, locomotives, track maintenance vehicles, and wayside devices. It is intended to lead to more economical, efficient, and safer train movement in North America.

To help assess the potential for the ATCS to provide positive train separation, speed restriction enforcement, and other safety enhancement functions, the Federal Railroad Administration tasked ITS to study the ATCS specifications and evaluate the system development process.

ITS concluded that the system development process to date has applied sound engineering techniques and the ATCS has the components to provide positive train separation. However, due to the complexity of the system, ITS also concluded that additional modeling, simulation, and field testing are required before the ATCS is implemented.

RECENT ITS PUBLICATIONS

U.S. Department of Agriculture Forest Service Eastern Region Strategic Telecommunication Plan, 1994-2003 (by Rust and Haakinson).

An Evaluation of the North American Advanced Train Control System (by Haakinson, Rust, and Garrity).

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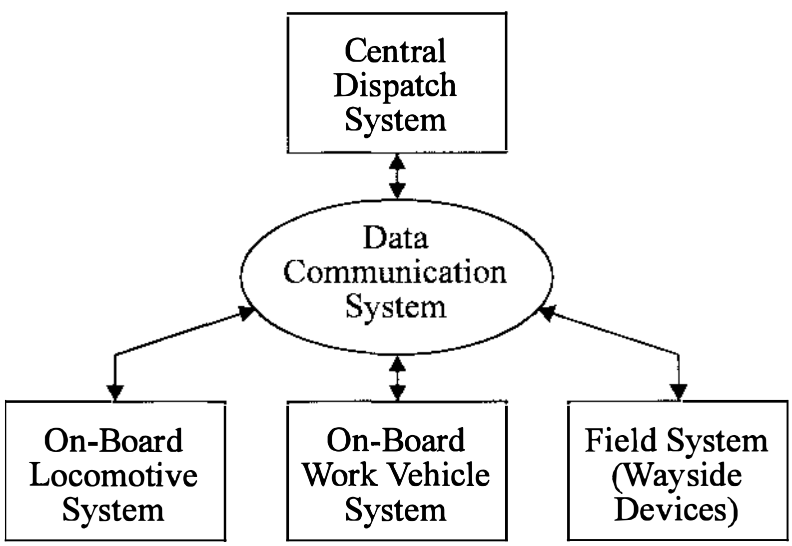

The Five Major Systems of the ATCS Architecture.

NATIONAL INFORMATION INFRASTRUCTURE PROGRAM PLANNING

OUTPUTS

- NII program plan of action.
- NTIA participation.
- Outline of short- and long-range objectives.

The National Information Infrastructure (NII) can empower U.S. industries and enrich U.S. citizens in many of ways, but full realization and wide distribution of its potential benefits will require focused Government action. NTIA has a major responsibility for promoting NII technology, innovation, and applications development through the Telecommunications Information Infrastructure Assistance Program (TIIAP). The TIIAP will enhance nonprofit private sector, local Government, and State Government activities by promoting beneficial and early implementations of the NII. These pilot implementations will, in turn, stimulate more widespread public use of NII capabilities.

The development of requirements for the NII is of utmost importance to the development of a comprehensive network architecture. A well-defined set of requirements will be based on the needs of users. Certain goals will also be set by thorough evaluations of public needs that can best be met by focused Government action. A key role of Government is to strengthen and, where necessary, supplement marketplace incentives for technology development and deployment.

The NII is envisioned as a "network of networks," starting with an integration of large networks already in existence, such as the Internet. Functional capability and connectivity will be expanded by integrating private and public networks and by enhancing these with wireless network capabilities. NII traffic will then see the global network as a seamless network; wireless and wired connections will be equally capable.

Once the needs and goals have been determined, a deliberate search for technology sources to fulfill these desires can begin. In many cases the technology required to fulfill a need is available or is under development. Through the TIIAP and related research activities, ITS is assisting public and nonprofit private organizations in identifying, developing, and applying core NII technologies.

As NII-enabling technologies are identified, proof-of-concept and feasibility testing may be required to determine whether these concepts will meet the defined needs. ITS is developing laboratory facilities that will enable contributions to the conduct of such testing, both at its Boulder Laboratories and at field locations established by NII technology developers. A major goal of this testing will be to ensure adequate quality of service to NII users. These activities will typically be conducted under cooperative research and development agreements with U.S. industry.

The ITS staff has participated in the development and advancement of the NII in several ways (Figure 1). In past years, ITS staff members have been actively promoting the development and international standardization of key technologies (e.g., integrated services digital networks, synchronous digital hierarchy, and asynchronous transfer mode) that are now providing the foundation for successful evolution of the NII. During the past year, ITS staff performed technical reviews of over 350 grant proposals submitted to the NTIA TIIAP Grant Program Manager. ITS has developed plans to support the TIIAP Program Manager in assessing and optimizing TIIAP projects actually funded. A key aspect of this work will be quantitative measurement of network performance to ensure optimal quality of service.

ITS also plans to take an active role in identifying and evaluating promising, but unproven, NII technologies and applications. ITS test facilities will be used to evaluate network performance, interoperability, interconnectivity, scalability, and efficiency in advancing NII technologies and applications (Figure 2). Many of the NII technology components and interfaces will be modeled in the ITS laboratories.

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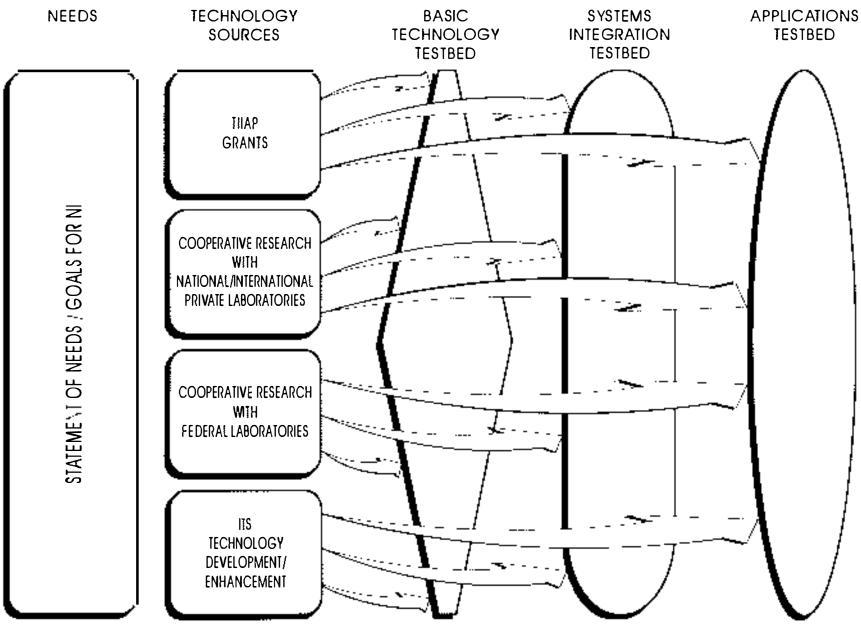

Figure 1. Areas of ITS Involvement in the NII Development and Testing Effort.

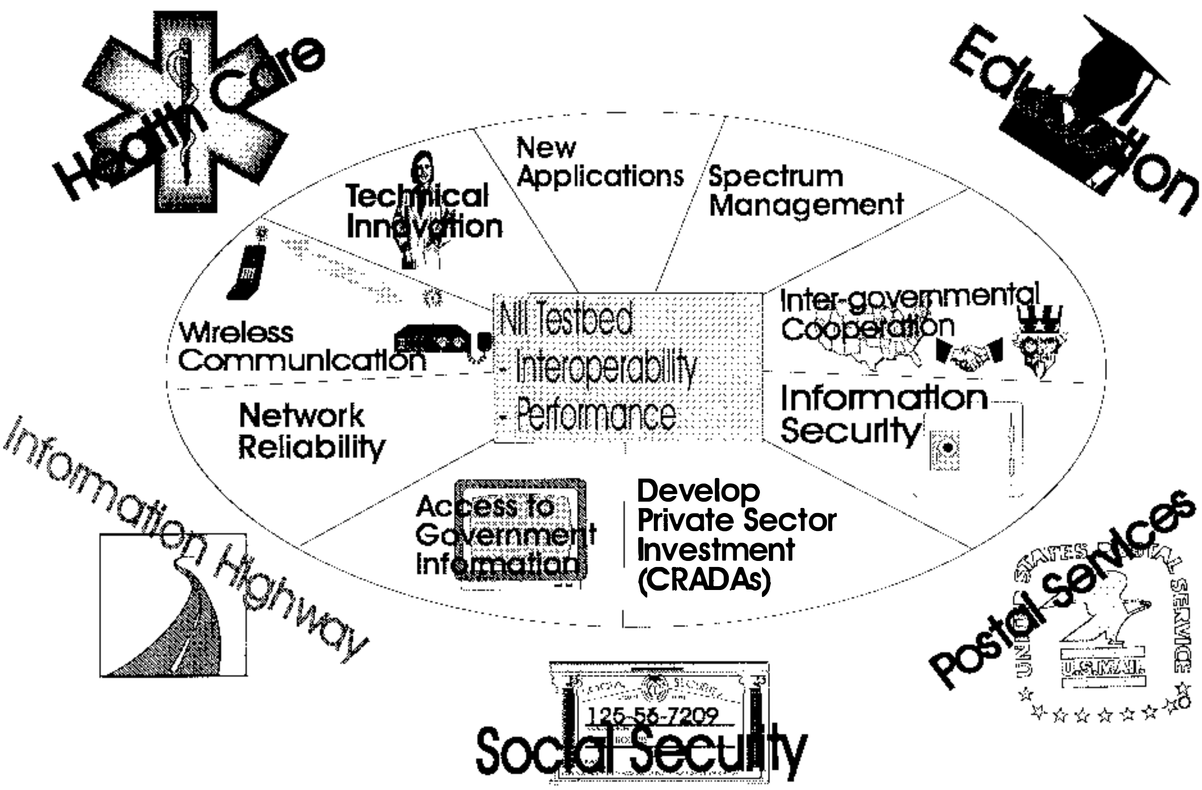

Figure 2. The NII Testbed - Focal Point for Cooperative Efforts between Government and Industry.

TELECOMMUNICATIONS ANALYSIS SERVICES

OUTPUTS

- Easy access for U.S. industry and Government agencies to the latest in ITS research results and to ITS engineering models and databases.
- Broad applications in telecommunication system design and evaluation of broadcast, mobile, link, and radar systems.
- Standard method of system analysis for comparison of competing designs for proposed telecommunication services.

Telecommunications Analysis Services (TA Services) gives industry and Government agencies access to latest ITS research and engineering on a cost-reimbursable basis. It uses a series of computer programs designed for users with minimal computer expertise or in-depth knowledge of radio propagation. The services are updated as new data and methodologies are developed by the Institute's engineering and research programs.

Currently available are: on-line terrain data with 3 arc-seconds (90 meters) resolution for much of the world and 5 minute resolution data for the entire world, the 1990 census data, Federal Communications Commission (FCC) databases, and Geographic Information Systems (GIS) databases (arcinfo). Other Government databases and reports will be available through a bulletin board service available to all users of TA Services as they are developed.

TA Services is currently developing models for GIS, personal communication systems (PCS), high definition television (HDTV), and intelligent transportation systems (ITS).

The following is a brief description of programs available through TA Services that perform user-requested calculations on-line and immediately send the output to a terminal.

PATH PARAMTRS - Calculates Great Circle distances and bearings between user-specified locations, and also provides delta-H and average terrain heights for those locations.

RAPIT - Gives the user on-line access to the latest in VHF/UHF propagation models. It can calculate basic transmission loss and other engineering information, such as received signal levels over irregular terrain for the design or analysis of broadcast and mobile radio systems. Program options allow the user to easily look at the effects the input parameters, such as antenna height, have on the received signal.

FMFIND - Lists the user-selected FM station engineering parameters from the FCC assignment database according to user-specified search parameters of location and distance.

TVFIND, **AMFIND**, and **TOWERFIND** - Returns the parameters for the respective TV, AM, or tower assignments/data according to user-specified search locations and distances.

INMOD - Calculates and lists intermodulation products in the user-specified receiver bandpass from up to 40 transmitters, 40 receivers, up to seventh order, and with up to five concurrently operating transmitters.

PROFILE - The Institute maintains a digitized topographic database of terrain elevations in various parts of the world. The data resolution is 3 arc-seconds (90 meters), and is generally derived from scaled maps of the Defense Mapping Agency. This program extracts path profiles according to user-specified input parameters, such as location and bearing. After the data is extracted, either the individual elevations or an average elevation along the profile can be obtained. The user can also receive plots of the profiles adjusted for various K factors depending upon the intended use of the path. For microwave links, Fresnel zone clearance can be easily determined from the plots so that poor paths can be eliminated from a planned circuit or network.

HORIZON - Plots the radio horizon around a specified location in the U.S. digitized topographic data. It is generally used for sighting of satellite terminals and radars so that terrain-shielding effects and limits on the elevations visible from the site can be determined.

SHADOW - Plots the radio line-of-sight regions around a specified location in the U.S. using digitized topographic data. It shows clear areas that are line-of-sight to the base of the antenna, grey areas that are line-of-sight to the top of the antenna, and black areas that are beyond line-of-sight to the antenna.

COVERAGE - Calculates the receive signal levels along radials that are spaced at user- defined intervals of bearing around the transmitter. The program lists the contours of signal coverage of the transmitter along each radial and lists distances to user-specified contours for each radial. Either the FCC Broadcast rules or the ITS irregular terrain model can be chosen for calculations.

CSPM - Determines the system performance of mobile and broadcast systems in detailed output plots of signal intensity, as shown in the Figure. Plotted outputs can either be FAXed directly to the user or plotted in brilliant colors on clear plastic to a specified scale for overlaying on widely available geopolitical maps. This is the most detailed of the signal calculation programs available and uses ITS' irregular terrain model in a point-to-point mode. The FCC rules, as well as other widely available models, can also be chosen. New models are placed on-line within CSPM as they become available. CSPM is capable of combining coverage from several transmitters to show the coverage from a network of stations. Another option allows interference regions to be plotted to determine potential interference from a user-specified transmitter within the area of interest. It shows the population, households, and areas covered within each of the signal ranges. The most ambitious use of CSPM to date involves determining the population covered by education television stations.

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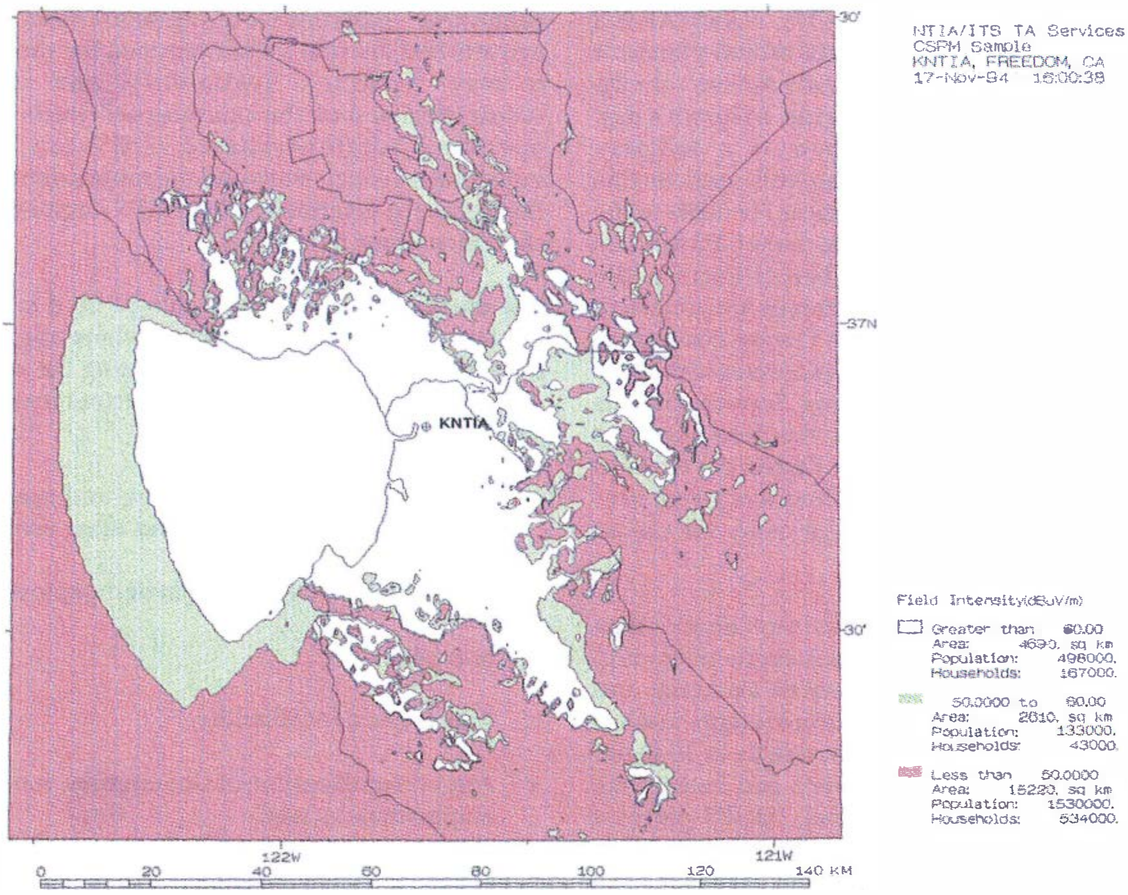

Example of TV Station Coverage Calculated Using CSPM.

AUGMENTED GLOBAL POSITIONING SYSTEM

OUTPUTS

- A recommendation for an augmented GPS to satisfy national positioning and navigation requirements.
- An implementation plan for the successful migration from the present navigation systems to the recommended GPS augmentation.
- Recommended standards and system specifications for an augmented GPS.

The NAVSTAR Global Positioning System (GPS) is a space-based radionavigation system operated for the Federal Government by the Department of Defense (DoD) and jointly managed by the DoD and Department of Transportation (DOT). NAVSTAR is a constellation of 24 satellites in six orbital planes; it provides accurate three-dimensional position, velocity, and precise time to users worldwide, 24 hours a day. GPS was originally developed as a military enhancement system. Although still used in this capacity, GPS also provides significant benefits to the civilian community. In an effort to make GPS services available to the greatest number of users while ensuring that national security interests are protected, two GPS services are used. The Precise Positioning Service (PPS) provides full system accuracy to military users. The Standard Positioning Service (SPS) is available for civilian use but has less accurate positioning capabilities than PPS. Each of the satellites transmits on the same L-band frequency and uses independent pseudorandom noise codes for spread spectrum modulation.

SPS' accuracy of 100 meters does not meet most civilian positioning requirements. Various augmentations to GPS are used to provide increased accuracy and integrity of the SPS signal. One form of augmentation, differential GPS (DGPS), can provide 1- to 10-meter accuracy for dynamic applications and better than 1-meter accuracy for static users. DGPS places a reference receiver at a precisely surveyed location, compares measured GPS satellite ranges with calculated ranges, and transmits a range correction signal to the user's receiver. Augmented GPS is expected to meet the navigation and positioning needs of the operating administrations of the DOT as well as most, if not all, Federal and state agencies.

ITS performed a study for the DOT to investigate and analyze the use of GPS with augmentation. A study review board comprised of representatives from the DOT, DoD, U.S. Coast Guard, Federal Aviation Administration, Federal Highway Administration, Research and Special Programs Administration, and National Oceanic and Atmospheric Administration provided oversight of the study. This study was undertaken to prevent an undesirable proliferation of different Federally funded GPS augmentations, to keep development and implementation costs as low as practical, and to keep user costs at reasonable levels. Currently available augmented GPS systems, proposed systems, and those under development were examined. Existing GPS augmentations (public, private, and foreign) were examined for their ability to meet accuracy, availability, and integrity requirements, and the operational needs of DOT operating administrations. DOT can use the independent conclusions and recommendations from this report to determine which GPS augmentation it should continue to support.

The results of this study will also be used to provide guidance and recommendations, where appropriate, to other Federal agencies investigating the use of, or operating, GPS augmentations. Factors used to rate the GPS augmentations included:

- ability to meet the requirements and needs of the operating administrations and other users,
- cost of Federal development and deployment,
- user cost,
- time frame of availability,
- effect on proliferation of Government-funded GPS augmentations, and
- ability to satisfy national security requirements regarding hostile exploitation of augmentation services.

In the first phase of the study, the navigation accuracy, availability, and integrity requirements of aviation, marine, and land modes of transportation, as well as positioning requirements of the surveying community, were gathered from the Federal agencies through a workshop and through personal contacts. Requirements of operational modes varied considerably. The positional accuracy requirement varied from 1800 meters for ocean navigation, to 1 millimeter for surveying deformation analysis. Technical specifications were obtained on several systems, including wide area/local area differential GPS, private sector differential GPS, geosynchronous Earth orbit satellite DGPS, Loran-C augmentation, beacons, triangulation, dead reckoning, and map matching. Foreign radionavigation systems such as the Global Orbiting Navigation Satellite System were also examined.

In order to evaluate the stated requirements for GPS augmentations, a weighted analytical decision matrix was developed that formed the basis for the final recommendations of the study. The matrix provided a method for organizing and displaying the data, as well as a method for obtaining relative performance scores for the augmentations considered. Results demonstrated that none of the present or proposed GPS augmentations satisfy the requirements of all operational modes. ITS proposed several system architectures that combine GPS augmentations to satisfy requirements of all operational modes. These combination architectures were then evaluated and the results were used to make the final recommendation.

ITS recommended that the Federal Aviation Administration continue to implement its wide area augmentation system (WAAS) and its local area DGPS (LADGPS) to satisfy aviation requirements for en route through Category I, II, and III precision approach. DOT, in coordination and cooperation with the Department of Commerce, should plan, install, operate, and maintain an expanded beacon system modeled after the U.S. Coast Guard's LADGPS to provide nationwide coverage for land and marine users. These DGPS systems will meet aviation user requirements for all phases of flight, marine user requirements for all modes of operation, and most land user requirements including requirements for intelligent vehicle highway system, railroad, and survey. Even the most comprehensive DGPS cannot provide uninterrupted coverage in all areas, as required by some modes of operation. The DGPS position solution requires the user to have a minimum of four GPS satellites in view, and be able to receive the differential correction signal. There are some locations such as urban canyons, mountainous terrain, bridges, and tunnels where the DGPS signals will not be available. In these locations it is suggested that the DGPS system be supplemented with inertial navigation, dead reckoning, map matching, or similar technologies.

The use of DGPS will have an enormous impact on a diverse set of uses including, aviation, ocean and land transportation, surveying and mapping, farming, waterway dredging, recreation, and many others that have not yet been identified. The use of DGPS will have an economic impact of tens of billions of dollars and the recommended systems will be implemented as soon as possible in order to realize these benefits.

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IMPACTS OF FOREIGN SOURCE DEPENDENCE ON THE TELECOMMUNICATIONS INFRASTRUCTURE

OUTPUTS

- Assessment of dependence on foreign sources for semiconductor devices, semiconductor factory equipment, and factory materials.
- Assessment of dependence on foreign sources for fiber optic devices and wireless personal communication systems.
- Analysis of factors related to the international competitive position of U.S. firms.

The ability to rapidly mobilize the telecommunications industry is critically important to National Security/ Emergency Preparedness (NS/EP) planning. As the agency primarily responsible for NS/EP planning, the National Communications System (NCS) determines the extent to which the U.S. telecommunications industry is dependent on foreign sources for key components. A heavy foreign source dependence could impede rapid mobilization under certain NS/ EP scenarios.

The Institute is supporting this effort by conducting a series of studies of foreign source vulnerabilities. In FY 94, ITS performed a broad assessment of foreign source vulnerabilities focused particularly on semiconductor devices and the factory equipment and materials used in their manufacture. The study also looked for foreign source vulnerabilities associated with fiber optic and wireless communication devices, which will become increasingly important to future NS/EP planning.

SEMICONDUCTOR DEVICES

The study identified a severe dependence on foreign sources for semiconductor devices. U.S. manufacturers lost their preeminence in semiconductor manufacturing during the 1980s (Figure 1). During that decade, the United States market share of integrated circuits fell from 60% to just over 40%. Although there has been a small rebound since 1991, as shown in Figure 2, U.S. telecommunications manufacturers obtain many of the semiconductors they use from foreign sources, particularly Japan.

Should it become necessary to increase semiconductor manufacturing capacity in the United States, factory equipment is readily available from domestic sources, but many manufacturing materials are predominantly or exclusively available from foreign sources. The study estimates that it would take one to two years to build a semiconductor process line and bring it to full production. This estimate assumes that needed materials obtained from foreign sources are still available.

1980		1990	
TI	1,580	NEC	4,952
Motorola	1,110	Toshiba	4,905
Philips	935	Hitachi	3,927
NEC	787	Motorola	3,692
National	747	Intel	3,135
Toshiba	629	Fujitsu	3,019
Hitachi	622	TI	2,574
Intel	575	Mitsubishi	2,476
Fairchild	566	Matsushita	1,945
Siemens	413	Philips	1,932
Total	$7,964M	Total	$32,557M

Figure 1. Top Ten Semiconductor Suppliers Worldwide (Courtesy of Sematech).

FIBER OPTIC DEVICES AND PERSONAL COMMUNICATION SERVICES (PCS)

The study did not identify dependence on foreign sources for fiber optic cable or related optoelectronic devices. U.S. manufacturers are in a good competitive position with their Japanese and European counterparts in terms of technology, price, and quality. However, this position is at risk because the U.S. Government invests relatively less on research and development in optoelectronics. As an emerging industry, it is difficult to assess how important the PCS market will become, and to what extent it will be dependent on foreign sources. However, it is likely the semiconductor source vulnerabilities will affect the PCS industry as well.

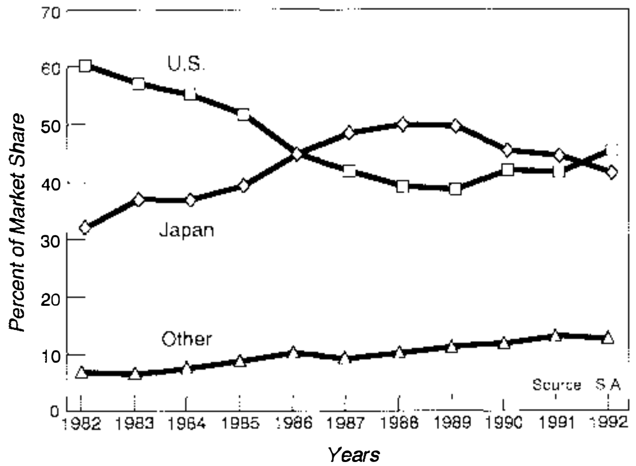

Figure 2. Worldwide Integrated Circuit Market Share of the United States and Japan, 1982-1992.

The study identifies a number of factors that may affect U.S. firms' competitive position, including:

- a focus on short-term return over long-term investment,
- U.S. tax structure and regulation,
- a significant time lag in adopting more efficient lean-production techniques,
- insufficient research and development funding, and
- lack of cooperation among U.S. manufacturers.

Over the last few years, there has been an increase in cooperation through industry associations and consortia, which may in part be responsible for recent gains by U.S manufacturers.

A final report was delivered to NCS and published in April 1994 as NCS Technical Information Bulletin 94-3.

RECENT ITS PUBLICATIONS

An Assessment of the U.S. Telecommunications Industry Dependence on Foreign Sources as it Impacts the U.S. Telecommunications Infrastructure (by Peach and Meister).

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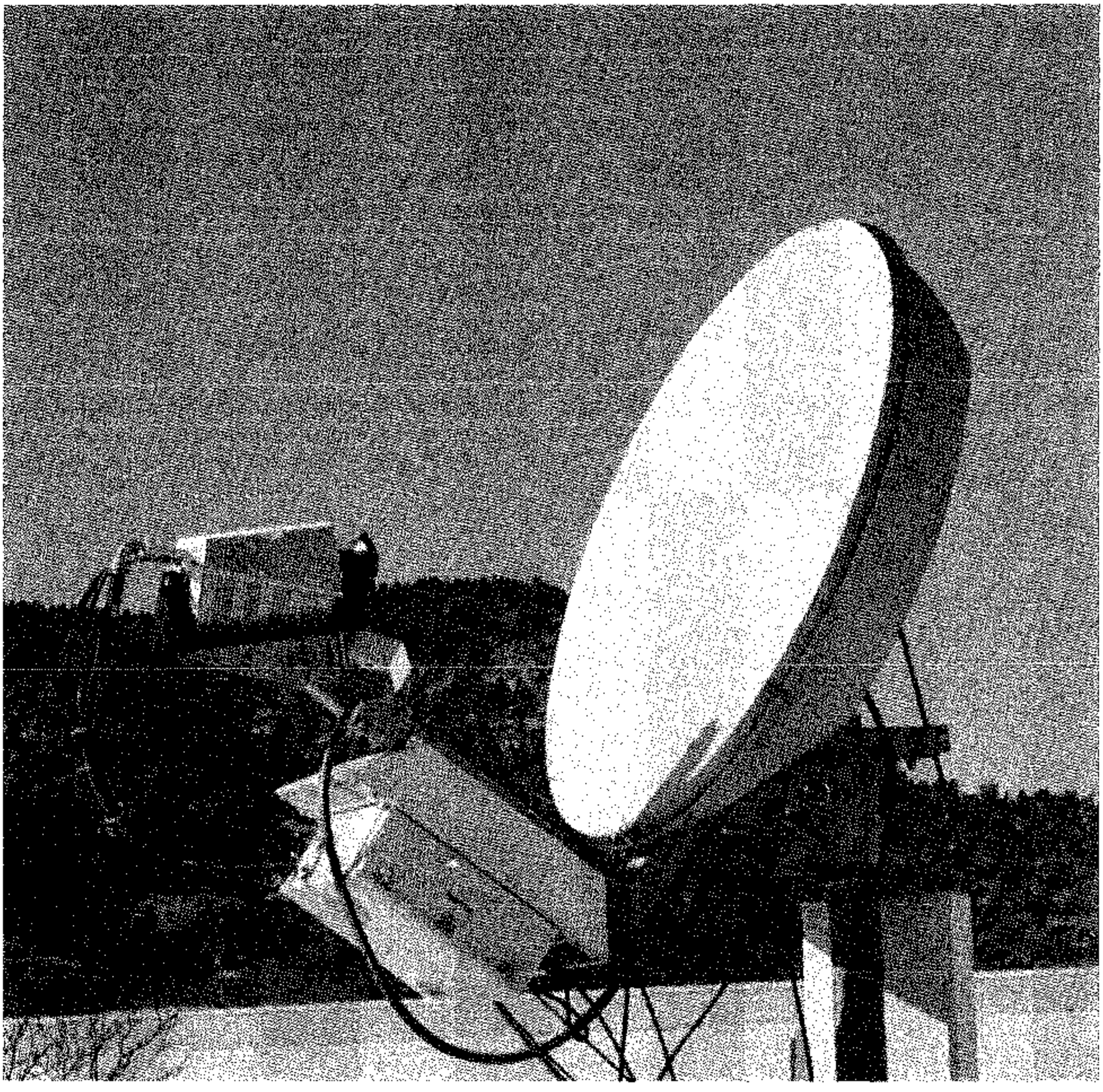

Advanced Communications Satellite Earth Terminal Antenna. *Photograph by D. Sutherland.*

TELECOMMUNICATION SYSTEM PERFORMANCE ASSESSMENT

ITS assesses the performance of a variety of communications transmission systems and computer communications networks. Assessment tools developed by the Institute include techniques used during the system-design process for predicting the performance of a telecommunication system in any specified operating environment. The set of tools also includes hardware and software test and measurement systems used to evaluate the performance of either prototype or operational networks and transmission systems.

These tools are used to test the performance of a variety of voice, data, and video telecommunication systems that are entire networks or specific transmission links.

The specific programs undertaken during FY 94 include investigations of transmission system performance in hostile jamming, interference, and fading environments. These programs address performance for a wide variety of transmission media including HF, VHF, UHF, millimeter-wave, and satellite transmission systems. Models and software are used to develop and verify transmission system design and to test advanced radio systems.

The network performance assessment programs undertaken in FY 94 produced unique tools for assessing data communications network performance and computer responsiveness in a heavily-loaded environment.

AREAS OF EMPHASIS:

Advanced Broadcasting Support
Includes projects funded by NTIA.

Army Reserve Component Automation System Testing and Evaluation
Includes projects funded by the U.S. Army Reserve Component Automation System Program Management Office.

Radio System Design and Performance Software
Includes projects funded by U.S. Army Ground Intelligence Center.

Satellite Studies
Includes projects funded by NTIA.

Advanced HF Technology: Modeling, Testing, and Evaluation
Includes projects funded by the National Communications System.

ADVANCED BROADCASTING SUPPORT

OUTPUTS

- Simulation of multipath-resistant transmission schemes with application to high definition television, digital audio broadcast, and simulcast operations.
- Impulse response measurement data from advanced television field trials.
- Standards support for subcarrier signaling from FM- and AM-broadcast stations.

ITS recently completed a simulation study of Orthogonal Frequency Division Multiplexing (OFDM), sometimes called "multiple carrier transmission." This transmission technique appears to be a promising means of mitigating adverse effects of multipath on high data rate digital radio communications. Over-the-air radio transmission at high data rates must contend with noise, interference, multipath, and other imperfections of the propagation channel. In the OFDM scheme, a stream of symbols is broken into blocks and each symbol of a block is used to modulate a separate carrier. For N evenly spaced carriers, the blocks will be of length N. The modulation rate on the separate carriers may be reduced to 1/N of the overall rate. There is no net change in the rate of transmission, nor in bandwidth requirements.

The presumed advantage of such a system lies in reduced rates of individual channels and their consequent resistance to multipath problems. Individual bandwidths are now narrow enough that all fading can be characterized as "flat." A guard interval between symbols is added to protect against intersymbol interference. Equally important, spectrum management is improved since the narrow bandwidths allow tight skirts to be placed at the channel edges (reducing adjacent channel interference problems). Also, the many carriers allow some flexibility in where their bandwidths are placed (helping to solve co-channel and intersystem problems).

ITS developed a computer simulation to model the performance of OFDM. After generating the bit stream, the resulting sequence of symbols is converted to a multiple-carrier modulation which produces a complex baseband signal. At this point in the simulation, additive gaussian white noise and interference from other systems or multiplicative noise caused by multipath are added to the signal.

The simulated receiver demodulates the composite signal with the following results:

- With only additive gaussian noise present in the channel, single- or multiple-carrier modulation behave the same; there is no signal quality benefit to using multiple-carrier modulation techniques such as OFDM.
- With multipath and noise present in the channel, multiple-carrier modulation is significantly better than the equivalent single-carrier modulation and can be close in performance to the ideal situation (no multipath present).
- With interference and noise present, multiple-carrier modulation can ignore or disable the carriers that lie on the stronger parts of the interfering signal. This again produces results that approach the ideal performance when only white noise is present.

Several examples of these findings are shown in the adjacent performance plots. Figure 1 shows the results for both a single-carrier modulation with quadrature phase shift keying (QPSK) and the simulated multiple-carrier modulation OFDM with QPSK and differential QPSK (DQPSK). Note that the results are essentially the same.

ITS has also modeled the use of OFDM in high definition television (HDTV). Figure 2 shows the performance of the HDTV receiver in a two-ray multipath environment with a 1-μs delay spread for a simulated OFDM using either QPSK or DQPSK modulation on each carrier. The figure also demonstrates the improvement when a 2-μs guard interval is inserted at the beginning of each block. The guard interval helps reduce the intersymbol interference that results in the multipath environment. With the guard interval, the performance curve for DQPSK in multipath and noise is nearly identical to the DQPSK performance in gaussian noise alone (as seen in Figure 1).

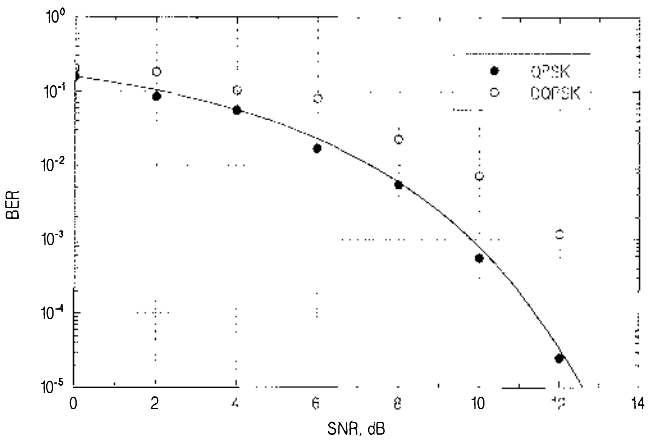

Figure 1. BER vs. SNR for a Simulated HDTV Signal Using OFDM and both QPSK and DQPSK Modulation.

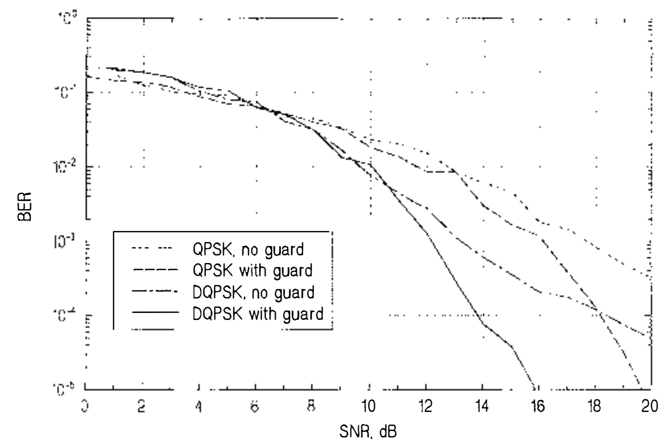

Figure 2. BER vs. SNR when the channel also suffers from two-ray multipath with a 1-μs delay spread.

Finally ITS has simulated an HDTV application using OFDM that will share the spectrum with a normal, co-channel NTSC television signal acting as interference. For the simulation, the bandwidth was 6 MHz and the number of multiple carriers was 384. To combat the NTSC interference, a "mask" was devised to delete OFDM signal frequencies surrounding the NTSC carrier, its chrominance subcarrier, and its audio carrier. Figure 3 shows the striking improvement. It should be noted that not only does the deletion of OFDM carriers aid the performance of HDTV receivers with NTSC interference, but it probably aids the performance of the NTSC receivers with HDTV interference.

The Federal Communications Commission has sponsored the Advisory Committee on Advanced

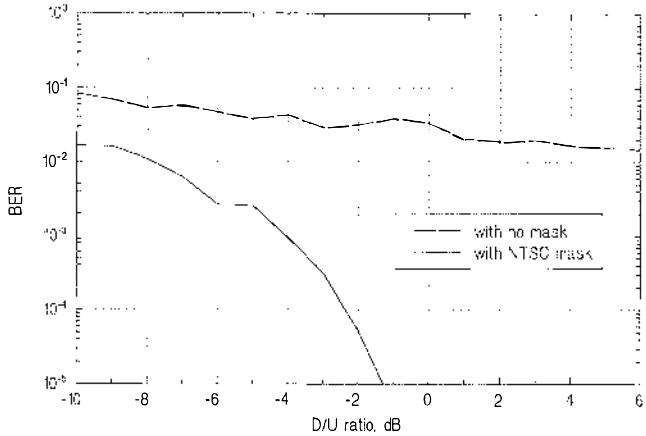

Figure 3. BER vs. desired to undesired ratio when an HDTV signal using OFDM suffers interference from an NTSC television signal.

Television Systems (ACATS), a joint industry/ Government effort to advise and oversee the various aspects of HDTV planning, development, and testing. This past year, the ACATS performed field tests in Charlotte, NC, on the Grand Alliance HDTV design. At each reception location for the tests, measurements of the HDTV system bit error ratios (BERs) were made. At the same locations, measurements to characterize the multipath environment were made. With the analysis of the data collected by ITS, the BER results can be correlated with the multipath environment.

ITS has participated on several Electronic Industry Association-National Association of Broadcasters committees that evaluate the use of AM- and FM-broadcast subcarriers as a means of providing traveler information. The subcarriers would have weather reports, road condition reports, and airport status information that could be received by special AM or FM receivers in cars or carried by individuals. ITS also has computed the coverage of the subcarrier signals to major highways from nearby FM stations. These coverage plots help show the potential of such a service to travelers.

RECENT ITS PUBLICATION

Orthogonal Frequency Division Multiplexing: An Application to High Definition Television (by Hufford).

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ARMY RESERVE COMPONENT AUTOMATION SYSTEM TESTING AND EVALUATION

OUTPUTS

- Test design plans.
- Test analysis reports.
- Independent evaluation reports.

The United States Army is developing and fielding the Reserve Component Automation System (RCAS) to fulfill long-standing plans to improve the operational readiness of the Reserve Component of the total force. The Reserve Component consists of the Army National Guard (ARNG) and U.S. Army Reserve (USAR).

The RCAS is a state-of-the-art automated information system that supports the decision-making needs of the commanders, their staffs, and the functional managers responsible for the operational readiness of the Reserve Component. The RCAS uses office automation, telecommunications, confederated databases, and distributed processing capability to accomplish routine administrative tasks and provide timely and accurate information to prepare and execute mobilization. It is a self-sufficient system capable of exchanging data with related information systems in the Active and Reserve Components.

RCAS is a sustaining base system. The RCAS will be used to manage the Reserve Component in support of units not deployed and for demobilization of individuals and units. The RCAS uses commercial off-the-shelf, state-of-the-art servers and RISC processors, commercial office automation software (word processing, electronic mail, spreadsheets, graphics, and desktop publishing), multilevel secure wide area network (WAN) telecommunications, specialized UNIX-based Ada application software, and a fully integrated relational database for every unit.

Local area networks (LANs) are being installed at approximately 9,800 ARNG and USAR units throughout the United States. Each of these LANs becomes part of the RCAS WAN that covers the entire United States and selected overseas locations.

ITS is responsible for performing the technical testing and independent evaluation of the RCAS solution. ITS is supporting the RCAS program management office by developing technical test plans, operating a technical test bed, and conducting a series of technical tests to evaluate the functionality, conformance with specifications, and performance of the RCAS as it is developed and deployed. The RCAS is being developed in "blocks" beginning with a foundation of commercial software and hardware and adding application software and technology enhancements incrementally.

During FY 94, there have been several maintenance updates to the fielded first release. ITS has performed a series of regression tests to assess the performance improvements and the functional corrections that are included in these updates.

The next release block in the RCAS evolution contains the first large increment of application software and supporting hardware to achieve automation and consolidation of the human resources functions within the Army Reserve and National Guard. In order to affect the human resources applications, as well as others, a suite of support software is needed for internal management of database information and flow, for the creation of forms and other user interfaces, for the distribution of network address information, and for the support of multilevel security. The basic network information transport protocol is also migrating from a TCP/IP environment to an Open System Interconnection X.400/X.500 mail and directory transport protocol. During FY 94, ITS prepared a series of test plans, test tools, and functional models to support performance and network tests on the product release.

One of the general capabilities of RCAS is the ability of users to concurrently perform administrative and support tasks on their own servers. ITS is utilizing a complex software suite designed to offer the automation servers the equivalent workload of many simultaneous users to load and test these servers.

The test tool is a Remote Terminal Emulation (RTE) software suite. In the RCAS solution, Graphic X-terminals exchange information with the server following a standard protocol. These user terminals are attached to the server through a LAN connection.

Each server is designed to support many X-terminals. The use of the RTE has enabled ITS to capture real user work scripts and to replicate and play back these scripts many times to simulate a large number of users simultaneously performing work.

The RTE process flow is shown in the Figure. The RTE server captures the LAN traffic generated by a single user performing a series of operations as defined in a work script. The RTE server can then play back the captured information to one or more Office Automation (OA) servers. To the OA server, each RTE user appears to be a live, consistent, and repeatable user.

Several different scripts can be captured and recorded by the RTE server. A mixture table can be developed, allowing each RTE user to perform a different series of scripts. This allows the tester to tailor the work load on the OA server to some accepted level and avoids the situation where all RTE users are performing the same operations at the same time. User think times may also be set to consistent, predetermined values to accurately reflect the response and speed of real users.

Each operation performed by an RTE user can be time-stamped. The response time of the system under test can be determined for various operations or transactions, as well as for various classes of operations. When the RTE users are running on a server under test, the server's loading in terms of CPU usage, memory usage, and disk access activity, is monitored and recorded.

Once testing is complete, the recorded response times and system loading information is reported as a series of plots and tables for use in system evaluation.

This tool is used in system performance testing to develop data that will ensure that the system is capable of supporting the designed number of concurrent users and providing each user with an acceptable responsiveness to all transactions. By performing system load tests of this nature, multiuser limitations can be detected and corrected at an early stage, rather than after equipment is fielded and the number of users builds up. This technique is particularly useful and beneficial in an environment as complex as RCAS where there are so many interactive, asynchronous functions active.

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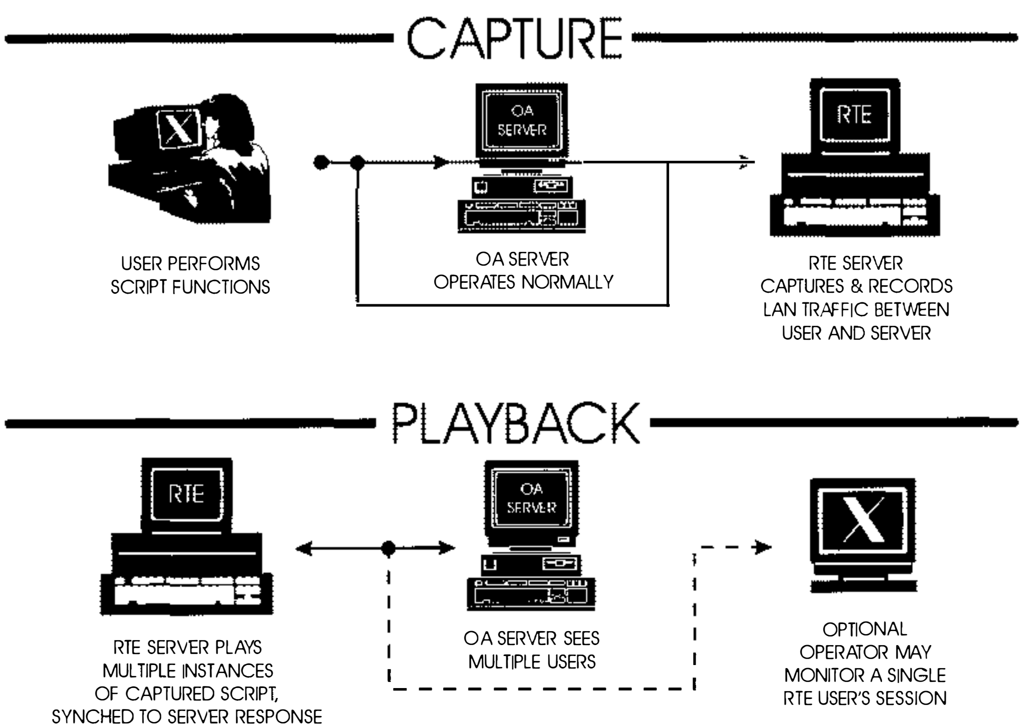

Remote Terminal Emulation (RTE) Process Flow.

RADIO SYSTEM DESIGN AND PERFORMANCE SOFTWARE

OUTPUTS

- Current version of JEM in use by the U.S. Army.
- Additional version of JEM under further development for the U.S. Army.

Advances in radiowave propagation modeling have continued at ITS in FY 94 with the improvement of the Jammer Effectiveness Model (JEM). This software program is user-friendly and menu-driven. The latest version of JEM runs as a Windows application. The extensive analysis and design capability of this program has previously been limited to mainframe computers.

The JEM software model is under development and primarily used by the U.S. Army to evaluate electronic warfare scenarios. This model is highly structured and modular in design, which allows for greater flexibility and expandability. The model includes a user-created catalog of equipment, ground stations, aircraft and satellite platforms, the software for creating and maintaining this catalog, a climatological database for much of the world, a library of propagation subroutines, and the analysis software. Current scenario types that can be analyzed are ground-to-ground, ground-to-satellite, ground-to-aircraft, aircraft-to-satellite, jamming from an airborne or ground jammer, and jammer versus network from an airborne or ground jammer. The communication links or network being jammed can have transmitters and receivers either airborne or ground-based.

The JEM propagation library includes subroutines for use in calculating clear air attenuation, rain attenuation, multipath attenuation, diffraction losses, troposcatter losses, and others.

In the current development phase of JEM, the frequency range is being extended downward below the microwave region. The frequency range covered by JEM will include 2 MHz to 300 GHz, extending the current 1- to 300-GHz range. A jamming and jammer versus network model are under development for integration into the JEM software model to extend the frequency range to 2 MHz.

The 2- to 30-MHz range will include propagation models for both ground wave and sky wave. The scenarios available in this frequency range include jamming from an airborne or ground jammer and jammer versus network from an airborne or ground jammer.

An irregular terrain model for the 20-MHz to 20-GHz frequency range is also being integrated into JEM. The scenarios available in this frequency range are jamming from an airborne or ground jammer and the jammer versus network scenario from an airborne or ground jammer.

The jammer effectiveness model includes scenarios for different combinations of transmitters, receivers, and jammers that are on the ground or carried by airborne stations. A jammer footprint is one type of analysis that can be performed in the jamming scenario (See the Figure). A jammer footprint is a polar plot of the minimum distance from the jammer versus azimuth angle about the jammer that a receiver/transmitter pair must be located to communicate in the presence of jamming.

RECENT ITS PUBLICATION

Software for the Analysis of Microwave Operational Scenarios (by Allen).

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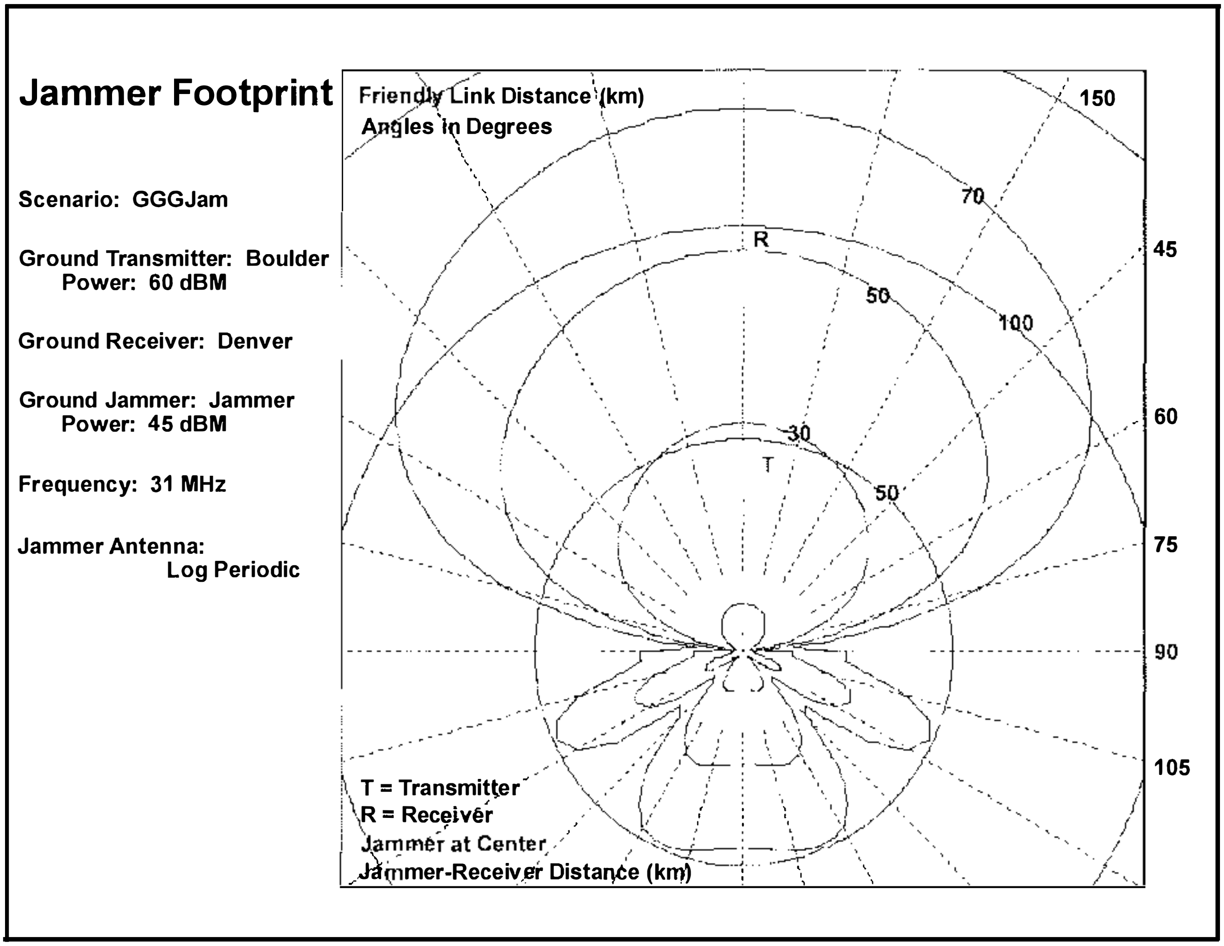

Example Output from the Jammer Effectiveness Model.

SATELLITE STUDIES

OUTPUTS

- Draft report on circuit-switched network performance.
- Packet-switched network model development.
- Performance measurements of ACTS.
- GOES-3 system engineering studies for PEACESAT.

As we move into the information age, access to and choices among telecommunications services are increasingly important to users. Universal access to a broad range of information sources may best be realized by using hybrid telecommunications networks (i.e., using networks that include both terrestrial and satellite components). Satellite systems may provide the only network access for remote areas and for areas where terrestrial facilities are underdeveloped or unavailable due to naturally caused or human-originated outages. Satellite systems may also be valuable when used with terrestrial systems. These ideas are illustrated in Figure 1. The growing number of choices among services and user-access methods increases the demand for interoperability, and this in turn means that many different internetwork interfaces must be defined. Integration of network management is also more important and more difficult in a hybrid network environment.

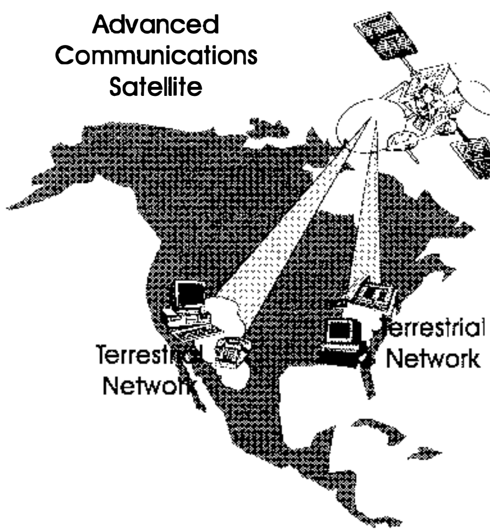

Figure 1. Advanced Satellite Communications Provide On-board Processing and Switching and Spot-beam Capability.

ITS pursues a program of satellite studies focused on the roles for advanced communications satellite technology in broadband communications networks and on the resulting requirements for performance, interface, and interoperability standards. During FY 94, this program included:

- further development of computer simulation modeling to understand effective integration of advanced satellite systems with broadband terrestrial systems,
- planning and conducting experiments to determine performance of the Advanced Communications Technology Satellite (ACTS), an experimental satellite system that contains technology features expected in operational satellite systems of the future, and
- system engineering studies of Geostationary Operational Environmental Satellite (GOES-3) capabilities for satisfying requirements of the Services Improvement Plan for the Pan-Pacific Education and Communications Experiment by Satellite (PEACESAT).

Two types of computer simulation are modeled. One is a simulation of large, circuit-switched networks. The objective of this effort is to better understand the benefits that advanced satellites may provide to restoration and continuity of service when damage or overloading occurs in the terrestrial network. In the second effort, ITS is developing a simulation model for packet-switched networks. Work is complete on a nonoverlapping packet generator, while modeling to determine cell-delay variation is well-advanced. These capabilities allow realistic estimates for required queue lengths and buffer sizes to avoid over-design in such network components as Asynchronous Transfer Mode (ATM) switches. More generally, the model will be available for the study of parameters in ATM networks and used in the development of standards for ATM networks and network components.

As a key player in the ACTS Experimental Program, ITS is making quantitative measurements of the ACTS performance. These measurements rely on standardized data communication performance metrics and measurement methods developed at ITS and adopted by ANSI. The ANSI standard defines 21 performance metrics that ITS instrumentation can measure under a variety of conditions. One of these metrics is access time, defined as the time between the first input by a user requesting access to the satellite and the beginning of actual user data transfer. This time reflects the ability of the satellite system to process a user request and allocate bandwidth to that user. Figure 2 shows a histogram of access times for 100 trials. The measured mean access time is 0.82 s. For comparison, the same measurement taken directly between the user terminals after removing the satellite from the system, gives a mean access time of 0.30 s. The difference approximates the propagation time associated with two transfers of call processing information across a synchronous satellite channel.

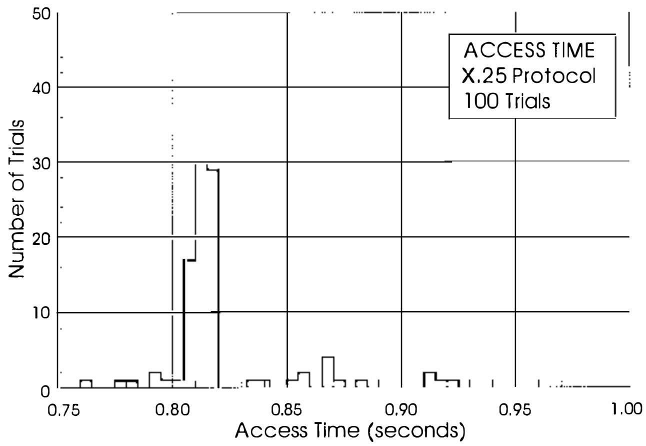

Figure 2. Access Time for a Circuit-switched Network over ACTS with No Other Users Active.

ITS is planning more sophisticated experiments based on a three-node network of Earth stations. These tests of processes and functions that involve multicast or complex interactive communications are not possible using the satellite simply as a relay station. These experiments will help determine how well the switching capability works on board the ACTS and how well certain applications perform over a switching satellite.

The PEACESAT network uses the GOES-3 satellite and single-channel per carrier (SCPC) narrowband FM technology to provide public service telecommunications (for emergency management, distance education, economic development, telemedicine, etc.) to about 35 user locations scattered throughout the Pacific. As the number of users grows and requirements for communication services increase, the services provided by the PEACESAT network will need to improve. During FY 94, ITS conducted system engineering studies to determine the extent of improved network services that can be expected by using digital technology as an "overlay" to existing analog technology. These studies showed that the satellite is power-limited rather than bandwidth-limited. Nevertheless, the satellite should support 37 carriers that can be used to provide a variety of network service (9 carriers for SCPC analog voice and voice-band data and 26 carriers for multiple channel per carrier digital services that include voice, data, and video). These services will be a significant improvement over the current situation of 16 carriers for SCPC analog services.

RECENT ITS PUBLICATIONS

Hybrid Digital Networks Using Optical Fiber and Advanced-Satellite Systems (by Jennings).

Satellite/Terrestrial Network Interface Technology (by Jennings).

Test Plan for Experiments to Provide Preliminary Characterization of ACTS Performance (by Weibel).

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ADVANCED HF TECHNOLOGY: MODELING, TESTING, AND EVALUATION

OUTPUTS

- Support to HF radio standards development.
- Audio compact disc for ALE interoperability testing.
- ALE emulation software on anonymous FTP.

HF radio has recently experienced a revival in popularity, due, in part, to technology advances such as Automatic Link Establishment (ALE) computer-controlled radios. The Institute has been in the vanguard of HF technology advances in several areas, including modeling, testing, and evaluation. ITS is developing both network and single radio HF models under the sponsorship of the National Communications System (NCS).

ITS personnel are currently developing an HF radio ALE network simulation capability based on proposed Federal Standard 1046, "Telecommunications: HF Radio Automatic Networking." The simulation programs will be used to study network performance, as an aid in preliminary evaluation of proposed standards features and changes, and in support of over-the-air network tests. These network simulation products will be useful to users, designers, and administrators in determining efficient network resource configuration and utilization. HF radio channel efficiency, throughput, and delay can be substantially improved through proper selection and use of newly-developed advanced network features and functions such as frequency scanning, sounding, polling, alternate or indirect routing, connectivity information exchange, automatic message exchange, and store and forward message exchange. However, due to overhead issues involved with their use, managers and administrators must use these features and functions sparingly. The results of simulation studies will allow network users and administrators to balance network use and channel condition monitoring for optimum network utilization.

Other simulation tools under development at ITS include an HF radio channel and modem simulator and an ALE radio network protocol simulator. These products are more completely described in the Tools and Facilities section on page 79.

During FY 94, staff members completed a model of ALE protocols based on Federal Standard 1045A, "Telecommunications: HF Radio Automatic Link Establishment," and applied that model in creating an ALE Clean Tones audio compact disc (CD). The ALE CD has been used successfully in laboratory testing and has been distributed widely in the HF radio industry. The ALE Clean Tones CD directly supports the continuing ITS function of HF radio performance and interoperability testing during FY 94.

The ALE Clean Tones CD has proven useful as an aid to HF radio vendors and users in interpreting and analyzing radio implementation of the Federal Standard. The ALE protocol is represented by lines of text in an ASCII file. The *alecall* program reads the ASCII text file and then creates a digitally encoded audio representation of the corresponding ALE tone sequence. The ASCII protocol files specify exactly how the digitally encoded call will proceed. The files detail all aspects of the call, such as the number of repeats of the preamble and address during the calling cycle, the slot times and expected responses of group and net calls, and pauses between communications. The *alecall* software that created the files recorded on the CD can also create sound files on a personal computer that may be played through a soundcard. Thus the program can be used to create ALE calls "on the fly" and used for real-time laboratory testing and analysis. This software is available to the public by anonymous FTP through the Internet.

The ALE Clean Tones CD can be used for laboratory testing by connecting the headphone jack output of a CD player or a soundcard output to the voice-activated input of an HF transceiver, with correct impedance matching. As a call is played on the CD or through the soundcard, the transceiver transmits it to an ALE radio. Thus, the ALE radio can be tested for all mandatory ALE functionality, including correct response, linking capability, and messaging abilities. Both the *alecall* output through a soundcard and the ALE Clean Tones CD through a CD player were used extensively in FY 94 in HF radio implementation testing and performance assessments. ITS also supports the High Frequency Industry Association and other Government agencies in improving the ALE Clean Tones CD to meet the needs of both HF radio users and vendors.

The *alecall* software was enhanced by the addition of simulated ionospheric propagation conditions to the ALE calls. Digital signal processing techniques are used to simulate degraded ionospheric conditions based upon the Watterson HF channel propagation model developed at ITS. A user may specify within the protocol file that the call be recorded with the addition of Gaussian noise, fading, or multipath conditions. These conditions, which are based on the Watterson model, are added to the output signal, as illustrated in the Figure. ITS plans to use an additional set of CDs containing degraded tones as source data for assessing radio system compliance with probability of linking statistics specified in Federal Standard 1045A. Corresponding Degraded Tones CDs, also targeted for performance and interoperability testing, will be distributed during FY 95.

Proof-of-concept (POC) testing for proposed Federal Standard 1052, "Telecommunications: HF Radio Modems" was also done in FY 94. POC testing and evaluation of the 1052 modems directly supported HF radio ALE Federal Standard development. ITS personnel were key contributors to 1052 modem assessment being done by the POC 1052 Working Group under the Federal Telecommunications Standards Committee.

Radio performance and interoperability testing is part of a continuing effort at ITS in its work for other Government agencies. Some of the equipment tested in FY 94 included the Department of Defense airborne ALE radios and HF radio packet modems. Evaluation is also proceeding on lower data rate digital modem protocols and on HF packet modem protocols with respect to throughput and errors.

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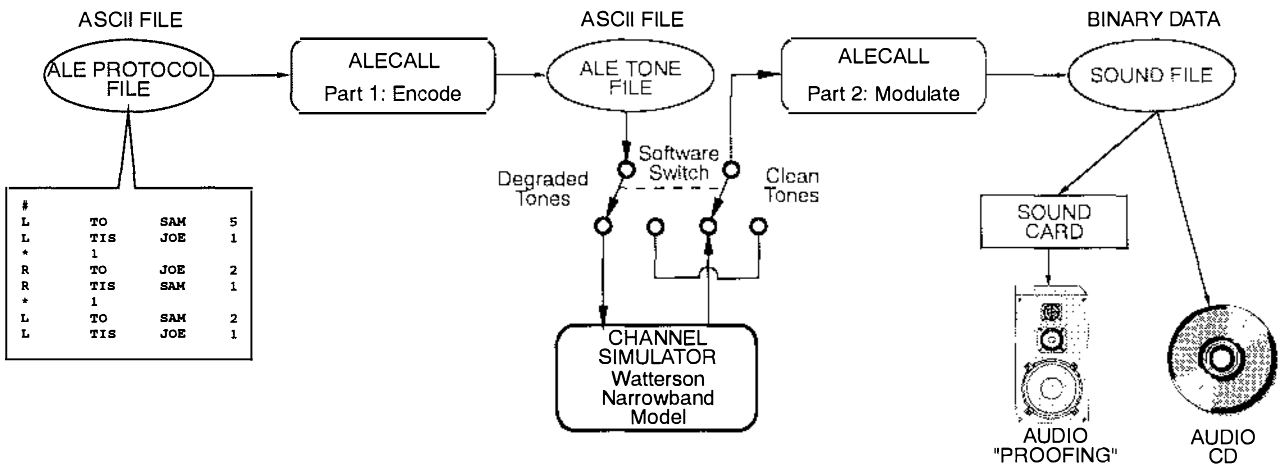

Software Techniques for Generating Sound Files of Clean or Degraded ALE Tones.

ITS Measurement Team Prepares to Move Out for Field Measurements in Support of Personal Communication Services Research. *Photograph by D. Sutherland.*

APPLIED RESEARCH

The rapid growth of telecommunications over the last 40 years continues to cause crowding in the radio spectrum, even though many telecommunications are now carried by fiber optic systems. New applications of technology have required a new understanding of the behavior of radio waves in all parts of the radio spectrum. Research at ITS includes studies of the lowest frequencies (LF noise measurements) to the highest frequencies in use (millimeter-wave modeling).

This work extends ITS' understanding of the ways that propagation of radio signals is affected by the earth's surface, the atmosphere, and the ionosphere. As a result, new propagation models for the broadband signals used in some of the new radio systems are being developed. Other efforts are increasing our understanding of the propagation of millimeter-wave frequencies; this provides a huge band for future expansion of new radio communication services.

The Institute has a long history of radio wave research and propagation prediction development that provides a substantial knowledge base for the development of telecommunication systems. A major goal of ITS is to transfer this technology to the larger telecommunication community, both public and private, where knowledge is transformed into new products and new opportunities.

AREAS OF EMPHASIS:

Cooperative Research with Industry
Includes projects funded by US WEST Advanced Technologies, Inc.; Telesis Technologies Laboratory, Inc.; General Electric Company; Motorola, Inc.; US WEST New Vector Group; and Superconducting Core Technologies.

Personal Communication Services Measurements
Includes projects funded by NTIA; US West Advanced Technologies, Inc.; Motorola, Inc.; US WEST New Vector Group; and Telesis Technologies Laboratory, Inc.

Personal Communication Services Research
Includes projects funded by NTIA.

Millimeter-wave Propagation Modeling
Includes projects funded by NTIA.

Wireless Link Error Modeling and Simulation
Includes projects funded by NTIA and the National Institute of Standards and Technology.

Wireless Link Simulation and Performance Prediction
Includes projects funded by NTIA, the U.S. Information Agency (Voice of America), and the Department of Defense.

COOPERATIVE RESEARCH WITH INDUSTRY

OUTPUTS

- A study of broadband millimeter-wave propagation research to assist in the evaluation, planning, and deployment of local multipoint distribution services.
- Measurements of channel impulse response from 800 MHz to 2 GHz for characterization of broadband propagation in urban and suburban microcells and macrocells.

The Federal Technology Transfer Act of 1986 (FTTA), as amended, allows Federal laboratories to enter into cooperative research agreements with private industry, universities, and other interested parties. The law was passed in order to provide labs with clear legal authority to enter into these arrangements and thus encourage technology transfer from Federal labs to the private sector. Under this act a cooperative research and development agreement (CRADA) can be implemented that protects proprietary information, grants patent rights, and provides for user licenses to corporations, while allowing Government expertise and facilities to be applied to interests in the private sector.

ITS is actively engaged in technology transfer and commercialization efforts by fostering cooperative telecommunications research with industry where benefits can directly facilitate U.S. competitiveness and market opportunities. ITS has participated for a number of years in CRADAs with private sector organizations. Research has been conducted under agreements with Bell South Enterprises; Telesis Technology Laboratories, Inc.; US WEST Advanced Technologies, Inc.; Bell Atlantic Mobile Systems; GTE Laboratories, Inc.; US WEST New Vector Group, General Electric Company (GE), Motorola, Inc., and Superconducting Core Technologies (SCT).

Much of the Institute's work in Personal Communication Services (PCS) has been accomplished through CRADAs. Not only does the private industry partner benefit, but the Institute is able to undertake research in commercially important areas that it would not otherwise be able to do.

ITS has had the opportunity to share in and contribute to a comprehensive PCS technology development program with Telesis Technology Laboratories, Inc. (TTL), a Pacific Telesis subsidiary. The Institute assisted TTL in the development of an experimental plan for spectrum use, signal strength, noise, and delay spread measurements.

As part of this agreement with TTL, ITS developed an innovative impulse response measurement system called a Digital Sampling Channel Probe. This system allows the measurement of the complex valued radio channel impulse response and is ideally suited for making outdoor impulse response measurements. The probe is capable of simultaneously transmitting two different pseudorandom noise codes, each with its own carrier frequency, antenna position, and antenna polarization. The receiver also provides a dual, independent channel design. The probe has been updated this year to include the capability for absolute time measurement and Doppler spread measurement. An example of the measured response is shown in Figure 1.

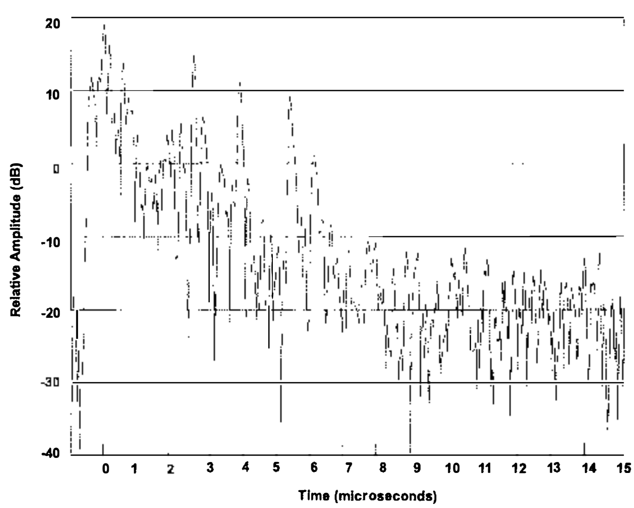

Figure 1. Example Power Delay Profile in an Urban High-rise Cell.

The Digital Sampling Channel Probe has been used this year to obtain channel impulse response measurements to characterize wideband radio propagation in a wide variety of environments and applications. Measurements were made in urban high-rise, suburban, rural hilly-terrain, and rural flat-terrain environments, and included investigation of features such as antenna diversity, Doppler shift, and angle of arrival. These measurements are described in more detail in the Personal Communication Services Measurements article on page 68.

ITS has been a premier laboratory in millimeter-wave research for two decades. This year ITS was able to apply this unique expertise to a study for TTL on radio propagation considerations for Local Multipoint Distribution Systems (LMDS). It has been proposed to put LMDS in the frequency band 27.5-29.5 GHz where equipment is not well-established and propagation effects are not entirely known. Several environmental factors affecting the over-the-air channel, including rain, clear air attenuation, vegetation, obstructions, and multipath, were reviewed in the study. Link budgets were calculated for LMDS in typical environments. Figure 2 shows an example link budget plot. The study also suggests areas that need more study.

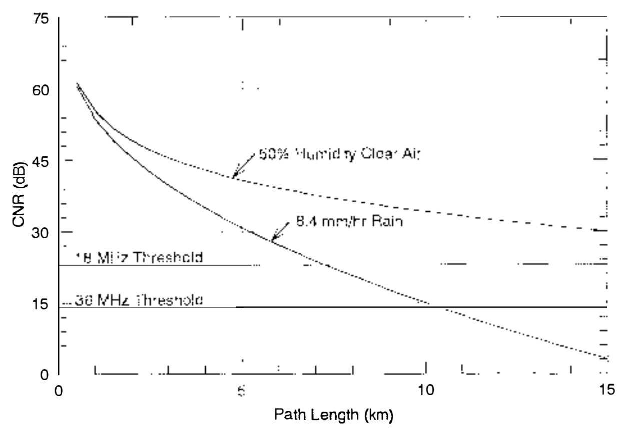

Figure 2. Example Link Budget Plot from the Los Angeles Area.

Also, in cooperation with GE, ITS investigated the RF emission characteristics of an RF-driven lighting device. Under this CRADA with GE, ITS measured the near-field and far-field emission characteristics of a newly-developed lighting device. The data generated by this study will be used by GE as part of a submission to the Federal Communications Commission (FCC).

ITS has entered into a cooperative research and development program with SCT, in the area of superconducting microwave devices. Under the CRADA with SCT, ITS will assist in testing the performance of devices for use in wireless communication networks, and consult on circuit designs and fabrication techniques to meet the defined performance specifications. Once filter and oscillator prototypes of appropriate performance have been developed, ITS and SCT will field test the prototypes. ITS will also cooperate with SCT in investigating the application of voltage tunable superconducting microwave filters and oscillators to improve the performance and reduce the cost of Government wireless communication systems.

Cooperative research with private industry has helped ITS accomplish its mission to support industry's productivity and competitiveness by providing insight into industry needs. This has led to adjustments in the focus and direction of other Institute programs to improve their effectiveness and value.

ITS is interested in assisting private industry in all areas of telecommunications as appropriate. The pages of this technical progress report reveal many technological capabilities that may be of value to various private sector organizations. Such organizations are encouraged to contact ITS if they believe that we may have technology that would be useful to them.

Because of the great commercial importance of many new emerging telecommunications technologies including PCS, wireless local area networks, digital broadcasting, LMDS, the national information infrastructure, and intelligent vehicle highway systems, ITS plans to vigorously pursue technology transfer to the private sector through CRADAs and thereby contribute to the rapid commercialization of these new technologies. In addition, ITS plans to commit substantial resources of its own to contribute to the development of these new technologies and standards.

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PERSONAL COMMUNICATION SERVICES MEASUREMENTS

OUTPUTS

- Addition of absolute time, Doppler spread, and improved resolution measurement (to 40 feet) capability to the newly-developed digital sampling channel probe.
- Impulse response measurements characterizing various macrocellular and microcellular environments in Boulder and Denver, CO; Seattle, WA; and Hong Kong.
- Comprehensive statistical data analyses of impulse response measurements including analyses to aid in the development of tapped delay line models of the channel.

Personal Communication Services (PCS) is an exciting new technology moving rapidly through the initial stages of development. PCS provides two major improvements in communication services. The first is portability. Many small cells can be used to provide low-cost telephone services through pocket-size, low-power, portable telephones to individuals wherever they may be within the service area. The other improvement is personalized telephone service. This requires an intelligent network that can provide customized service under the user's control. For example, the user may notify the network that until further notice they will accept voice messaging from all callers except selected numbers which they will answer immediately and personally.

The noise and interfering environments as well as the characteristics of the radio propagation channel in which PCS systems are likely to operate are not well-known. Knowledge of these environments and their characteristics is needed for the design and development of PCS systems as well as for the development of proper regulations and policies for these systems. PCS measurements play an important role in providing much of this information.

ITS' work in PCS measurements in FY 94 centered around impulse response measurements of the radio propagation channel. The impulse response of the propagation channel is of great importance in the design, development, and planning of radio systems since it completely describes the radio propagation channel. With the knowledge of the noise and interfering environment, these measurements can be used to predict radio system performance.

During the past year, several different impulse response measurement experiments were conducted for PCS applications using a digital sampling channel probe recently developed by ITS and Telesis Technology Laboratories, Inc. (TTL). The probe is ideal for making outdoor impulse response measurements. It currently has the capability of simultaneously transmitting two different pseudorandom noise codes. Each code can be transmitted with its own carrier frequency, antenna polarization, and antenna location. The computer-controlled receiver is also a dual-channel design and like the transmitter, each channel has a unique combination of carrier frequency, antenna polarization, and antenna location.

Three major enhancements were made to the digital sampling channel probe. These improvements included the addition of both an absolute time measurement capability and a Doppler spread measurement capability. The resolution of the channel probe was improved to identify reflections differing in path length by as little as 40 feet. When this resolution is not good enough (for indoor measurements), ITS uses an analog sliding correlator channel probe with a resolution as fine as 2 feet.

Much of the work in PCS measurements at the Institute this year has been through cooperative research agreements with industry. In a cooperative research agreement with TTL, mobile impulse response measurements were taken with a 20-MHz bandwidth in the 1850-1990 MHz band in three different macrocellular (cell radii of 5 km) environments in the Boulder/Denver area. A comprehensive set of statistical data analyses was performed including maximum and mean delay, RMS delay spread, correlation bandwidth, number of significant paths, path arrival time and power, amplitude statistics at each delay time, and analysis of spatial diversity. Figure 1 shows the results of a spatial diversity analysis for the urban high-rise cell. This figure shows that some decrease, although not large, in RMS delay spread values can be obtained using diversity combination. Figure 2 shows the cumulative distribution of the number of paths in an urban high-rise cell for several different thresholds. These results show the strong dependence of the number of paths on threshold level. This type of plot also shows how many taps should be used in a tapped delay line model to adequately represent the impulse responses seen in a given environment.

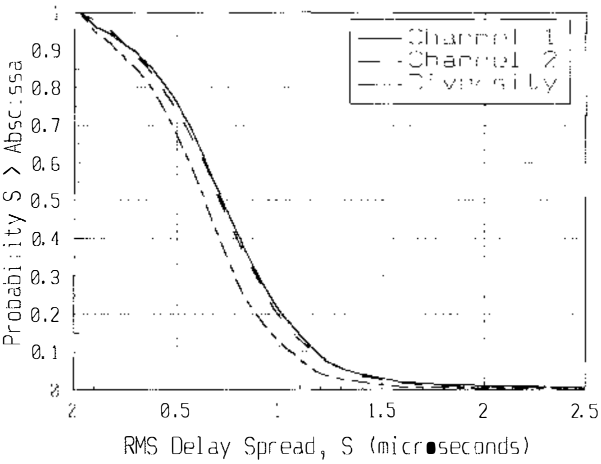

Figure 1. Effects of Spatial Diversity in an Urban High-rise Cell.

In another experiment, mobile impulse response measurements were taken in the 902-928 MHz band in six different cells (cell radii up to 5 km) in the Seattle area. A 20-MHz bandwidth was used for most of these measurements although some data were taken using a 2.5-MHz bandwidth. These measurements were performed as part of a cooperative research agreement with US West New Vector Group to provide a propagation database to analyze the performance of a prototype code division multiple access (CDMA) system.

Mobile impulse response measurements were taken in seven different cells in Hong Kong at 844 MHz using a 2.5-MHz bandwidth as part of a cooperative research agreement with Motorola, Inc. The objective of these measurements was to help Motorola, Inc. satisfy licensing requirements for the deployment of a CDMA system in Hong Kong. The requirements included a wideband propagation study in the area where equipment was to be deployed. Data were analyzed to provide RMS delay spread, correlation bandwidth, and multipath power statistics. Median RMS delay spreads ranged from about 0.4 to 0.7 microseconds with peak delays occasionally occurring out to 14 microseconds.

As part of a cooperative research agreement with US West Advanced Technologies, Inc., impulse response measurements were made in the 1850-1990 MHz band using a 50-MHz bandwidth in small cells (0.5-1.5 km radii) within several different environments in the Boulder/Denver area. These measurements were substantially different than the other measurements performed this year since they were taken at walking speeds and included measurements of Doppler spread. Some measurements were also taken simultaneously on two channels with a directional receive antenna on one channel and an omnidirectional receive antenna on the other channel so that the differences in the impulse responses could be studied.

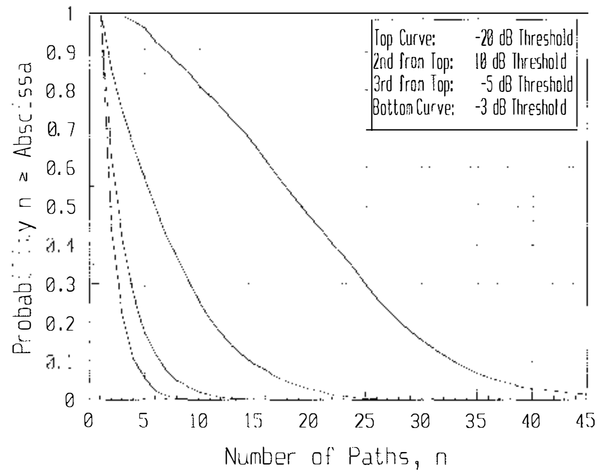

Figure 2. Number **of Paths in an Urban High-Rise Cell.**

RECENT ITS PUBLICATIONS

Characterization of Macrocellular PCS Propagation Channels in the 1850-1990 MHz Band (by Wepman, Hoffman, and Loew).

Impulse Response Measurements in the 1850-1990 MHz Band in Large Outdoor Cells (by Wepman, Hoffman, and Loew).

Radio Propagation into Buildings at 912, 1920, and 5990 MHz Using Microcells (by Aguirre, Loew, and Lo).

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PERSONAL COMMUNICATION SERVICES RESEARCH

OUTPUTS

- Analysis of indoor radio channel propagation measurements at 5.8 GHz.
- Analysis of the required coordination distance between PCS providers and fixed microwave operators in the 1850-1970 MHz band.
- Development of both a geometric optics model and an energy decay model for predicting the impulse response in an indoor radio propagation channel.

PCS research at the Institute is focused on providing an increased understanding of these environments and characteristics. Research in FY 94 included the development of both a geometric optics model and an energy decay model for predicting the impulse response in an indoor radio propagation channel, an analysis of indoor radio channel propagation measurements at 5.8 GHz, an analysis of the required coordination distance between PCS providers and fixed microwave operators, and a study of the noise and interference environment for PCS. A technical report on this work is forthcoming.

The Mobile Impulse Response Generator (MIRG) is a geometric optics model of an indoor radio propagation channel that was developed at the Institute this year. This model is implemented on a personal computer and calculates the impulse response of an ideal indoor channel, for a geometrically-defined ideal room. The receiver or transmitter may move about the room, providing the model with a mobility parameter. A recursive imaging algorithm is used to find all possible rays with up to twenty bounces; the free space loss and polarization dependent complex reflection coefficients define the amplitude and phase change of each ray as it travels from the transmitter to the receiver. Typically, impulse responses generated using up to five reflections provide a sufficient description for an indoor channel; the 20-bounce capability allows for the study of special cases, such as metallic rooms and anechoic chambers at frequencies below 80 MHz. The output of this model can be easily used as a channel model in radio system software simulation. Figure 1 shows an example output; the magnitude of the impulse response at 20 positions along a 35.4 meter path.

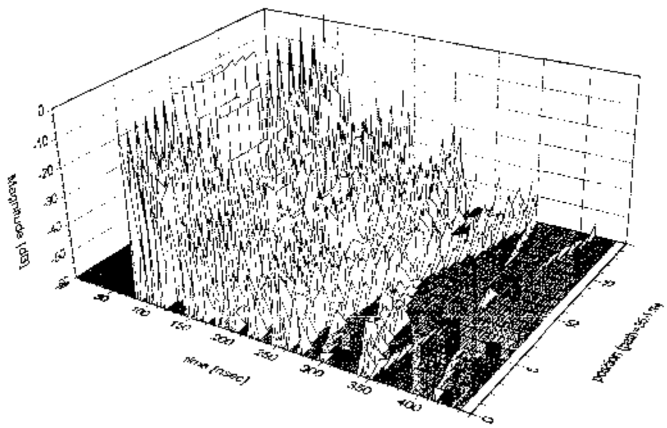

Figure 1. Magnitude of the Impulse Response at 20 Positions Along a Path.

An energy decay model based on reverberation theory is currently under development at ITS. This model allows prediction of electromagnetic energy decay inside a room. The decay rate is a measure of the average magnitude of the impulse response of a room. Once the energy decay rate is determined, it can be related to the magnitude of the impulse response of a radio signal propagating in a room.

The input parameters to this model are the room dimensions and the material properties of the walls, ceiling, and floor. One advantage of this model is the fast execution time; results can be obtained in a matter of seconds on a personal computer. The model is presently being validated by comparing its output to measured impulse response data from two different rooms. Enhancements to the model that are being investigated include the capability of incorporating objects within the room and the capability of coupling energy into and out of adjacent rooms.

An analysis of impulse response data taken at 5.8 GHz in a warehouse environment was performed. The data were taken using a corner-mounted, vertically polarized, omnidirectional receive antenna and an antenna mounted on a mobile transmitter. Thirteen impulse response measurements were made at specific locations throughout the warehouse. At each location, 12 impulse response measurements were made using both a horizontally and vertically polarized directional transmit antenna at six distinct azimuthal orientations (0, 60, 120, 180, 240, 300 degrees). Additionally, a single impulse response measurement was made using an omnidirectional transmit antenna at each location.

Figure 2 shows the RMS delay spread (at one location) for both the horizontally and vertically polarized directional transmit antennas at each of the six azimuthal orientations. The RMS delay spread for the omnidirectional transmit antenna is also shown. In this case, both the horizontally- and vertically-polarized directional antennas (for every azimuthal orientation) show smaller RMS delay spreads than the omnidirectional antenna.

An analysis was performed to evaluate the coordination distances, as established by the Federal Communications Commission (FCC), between incumbent fixed microwave operators and the new PCS providers in the 1850- to 1970-MHz band. The purpose of this analysis was to determine whether different criteria could be used to reduce the coordination distances established by the FCC. Reduction of the number of coordinations that must be performed by potential PCS providers is desirable since performing the required coordinations can be both costly and time consuming. The results of the analysis are currently being incorporated into an NTIA report.

Another NTIA Report to be published in FY 95 presents a summary of the available measurement information on the level and statistical characteristics of the background noise environment that PCS systems would encounter in the 1- to 3-GHz frequency range. Natural and man-made unintentional radiation are discussed, including both the overall background noise and noise from individual sources. The urban noise environment in this frequency range is dominated primarily by automotive ignition systems. The noise is non-Gaussian in character, but not highly impulsive. Nearby individual devices can produce noise at levels well above the overall background noise. Results for devices such as transformer substations, corona and gap discharges from high voltage transmission lines, welders, and electromechanical solenoid-type relays are given in this report.

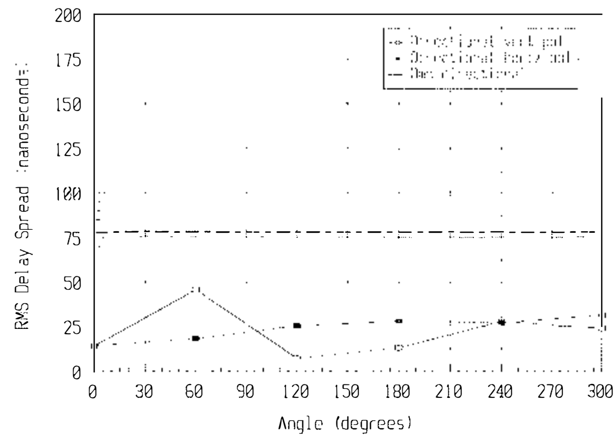

Figure 2. RMS Delay Spread for Various Transmit Antennas and Azimuthal Orientations.

In this report, a physical/statistical model was suggested to combine the background noise and interference with interfering co-channel signals to obtain the overall statistical interfering environment. The report clearly identified that the current knowledge of the noise and interfering environment for PCS is insufficient. Additional measurements are required to adequately characterize the background noise environment for PCS.

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MILLIMETER-WAVE PROPAGATION MODELING

OUTPUT

- Update of the millimeter-wave propagation model (1 - 1000 GHz).
- Update of the Zeeman-effect propagation model (50 - 70 GHz, and 119 GHz).

The millimeter-wave propagation model (MPM) computes the spectral properties of air, water vapor, suspended water/ice particles, and rain for frequencies between 1 and 1000 GHz in terms of complex refractivities or path-specific attenuation and delay rates. A local line-by-line scheme for H_2O (34) and O_2 (44) absorption is supplemented by an empirical water vapor continuum. The variables describing the atmospheric state are pressure, temperature, relative humidity, cloud liquid water (ice), and rain rate. The parametric nature of the MPM allows predictions of atmospheric transmittance and radiative transfer for different climatic conditions. The absorber distribution can be integrated along a radio path known from meteorological data.

Atmospheric transmittance in the 50- to 70-GHz band and around 119 GHz is dominated by the spectral line behavior of molecular oxygen. With increasing altitude, the widespread pattern changes from an unstructured band (approximately 8 GHz wide) into a series of about 35 isolated lines (several MHz wide) each affected over the height range from 30-120 km by the terrestrial magnetic field.

The Zeeman-effect Propagation Model (ZPM) computes, for conditions from 30-120 km, the transmission and emission behavior in the vicinity of the O_2 absorption lines. Within the Zeeman region, the geomagnetic field and its orientation with respect to the direction of propagation are considered as additional variables since magnetic strength varies substantially over the earth (22-65 microtesla). Anisotropic medium characteristics are present over a band of about ±5 MHz around each line center frequency.

The ZPM allows the user to display many aspects of polarized radio wave propagation through this medium and to study the consequent effects. A complex refractivity tensor, specific attenuation rates, Faraday rotation, polarization state (Stokes parameters), path transmittance, and the emitted thermal radiation are computed for ray-path geometries through a spherically stratified model atmosphere (0 - 130 km). All polarization states can be considered, especially the special circular and linear cases. The ZPM applies the density profile of the U.S. standard atmosphere, extended to 130 km and supplemented by height profiles of the absorber mixing ratios (O_2 and H_2O). The three components of the magnetic field are obtained from the international reference geomagnetic field (IRGF85).

Absorptive line properties also imply the presence of thermal emission spectra. ZPM predictions were tested with emission data from the 9+ line, centered at 61.150 GHz. The data were measured by a Millimeter-wave Atmospheric Sounder (MAS), a limb-sounding radiometer operated during the NASA ATLAS-1,2 and 3 space shuttle missions in March 1992, April 1993, and November 1994. One unique feature is the high-resolution (20 channels each 200 kHz wide) of the MAS radiometric spectrometer, which allowed for the first time a detailed comparison with predictions of the mesospheric Zeeman effect. Data samples from max/min magnetic field locations showed good qualitative agreement including evidence of polarized noise emitted by the atmosphere.

Using the ZPM (Hufford and Liebe, 1989; Liebe et al. 1993) to reproduce the limb-path geometry of the MAS experiment, a comparison was made between model predictions and measured data of the atmospheric brightness temperature emitted by the O_2 molecule at 61.1506 GHz. Two one-minute data samples are depicted in Figures 1 and 2. The symbols represent brightness temperatures measured over a bandwidth of 200 kHz. The polarization of the MAS receiving antenna was horizontal linear. The receiver operated in a double-sideband (DSB) mode.

ZPM predictions of brightness temperature (lines) are compared in Figure 1 with MAS measured data (symbols + lines) as a function of the frequency deviation (in MHz) from the line center of the 61-GHz

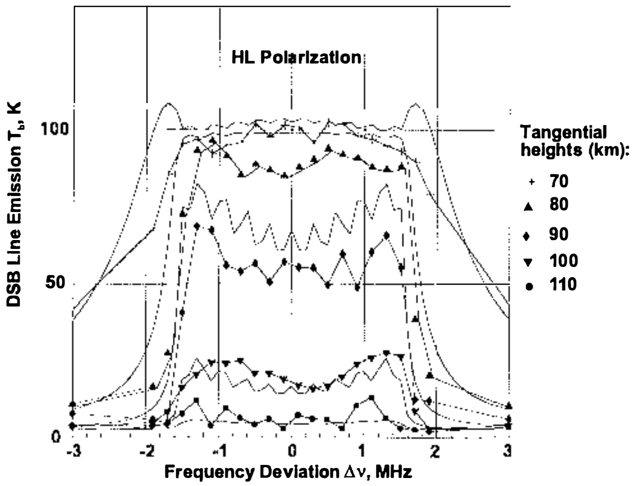

Figure 1. **Emission Signature of the 9+ Oxygen Line at 65°N, 103°W (Maximum Magnetic Field).**

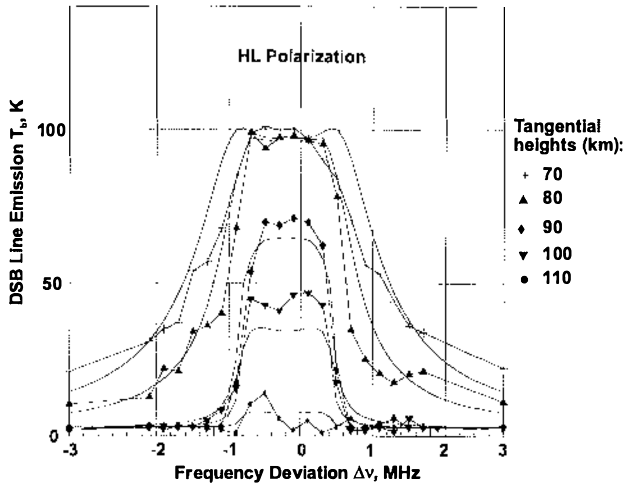

Figure 2. **Emission Signature of the 9+ Oxygen Line at 27°S, 33°W (Minimum Magnetic Field).**

O_2 line. A northern location with the coordinates 65° N and 103° W for the tangent point was chosen, where the flux density of the magnetic field was 58.4 microtesla (max) at a tangential height of 80 km. Figure 2 gives the same emission data at the coordinates 27°S and 33°W, where the flux density was only 23.7 μT (min) at a tangential height of 80 km. The distinct difference between Figure 1 and Figure 2 demonstrates that Zeeman splitting is proportional to the magnetic strength.

The relatively small discrepancies between data and predications stem from several factors, including:

- limitations of the model atmosphere,
- uncertainties in the 61-GHz/71-GHz DSB detection sensitivities of the MAS receiver (a ratio of 1:1 was assumed),
- incorrect heights of the tangent point when evaluated using the shuttle's navigation data, and
- imperfect spacings of the 200-kHz filters.

A comparison between data and the model revealed that a horizontally linear-polarized (HL) emission was received. MAS measured from space polarized noise originating in the mesosphere. Extensive data evaluations implied that the difference signal between MAS and ZPM holds valuable information. The mean of the variance of the residuals was about 1 K between 70 and 100 km height (approximately 3 K below 70 km). In the 60-GHz band, oxygen line emissions detected by limb-scanning can serve as a remote sensor of height profiles for the neutral gas density with a resolution better than 1 km.

RECENT ITS PUBLICATIONS

Propagation Modeling of Moist Air and Suspended Water/Ice Particles at Frequencies below 1000 GHz (by Liebe, Hufford, and Cotton).

Zeeman Splitting of the 61 GHz (9+) O_2 Line in the Upper Atmosphere Measured by MAS (by Hartmann, Degenhardt, Zwick, Liebe, Hufford, and Cotton).

Zeeman Splitting of the 61 GHz Oxygen (O_2) Line in the Mesosphere (by Hartmann, Degenhardt, Zwick, Liebe, Hufford, Cotton, Bevilacqua, Olivero, Kämpfer, and Langen).

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WIRELESS LINK ERROR MODELING AND SIMULATION

OUTPUTS

- Statistical bit error model for wireless network links.

ITS is currently collaborating with the National Institute of Standards and Technology (NIST) in the conduct of National Information Infrastructure (NII) research and evaluation. The wireless communications performance benchmarking program includes the development of a statistical bit error model serving as a demonstration of technology that could be used in higher level network simulations.

Wireless network performance simulation depends on knowledge of the time-varying statistical distribution of bit errors for each wireless link represented in the network. The distribution is a function of all the link variables, including the channel, noise, interference, modem, coding, and equalization. The Institute has developed a wireless link bit error model that enables mapping of the link variables into model parameters. The model is based on a Markov chain with two states: G (for "good") and B (for "bad"). In state G, transmission is error-free. In state B, the link has probability h of transmitting a bit correctly. State transition and bit transition diagrams representing the model, often referred to in the literature as the Gilbert model, are shown in Figure 1.

Because the bit transition probabilities depend on the states of a Markov chain, the model generates sequences of errors that are bursty in nature. This is important, because many link impairments, such as impulsive radio noise, switching transients, and multipath fades, cause the bit errors to occur in isolated bursts. For suitably small values of the probabilities p and P of state transitions, the model simulates the burstiness of errors that occur on real links.

The model development is based on error sequences derived from waveform simulations of link performance with various modems operating under varying propagation, noise, and interference conditions. Values of the model parameters are obtained by analyzing the distributions of the lengths of error bursts and error gaps (error-free intervals). Mathematical expressions have been developed for the means and variances of the error burst and error gap distributions of the model as functions of the model parameters. Constraining the means and variances to the values obtained from waveform simulations uniquely determines values of the state transition and bit error probabilities corresponding to a given set of link conditions.

Examples of error gap and error burst distributions obtained from a waveform simulation and from the statistical model are shown in Figure 2. The link conditions correspond to a binary frequency shift keying modem operating over a land mobile radio link with multipath delays at 8 μs and 15 μs and a symbol error rate of 0.005. The simulated and modeled distributions are quite similar; however, the calculation with the statistical model ran approximately 50,000 times faster than the waveform simulation. Thus, the model enables rapid evaluation of link performance for evaluation of voice, video, and data quality and for expediting network simulations.

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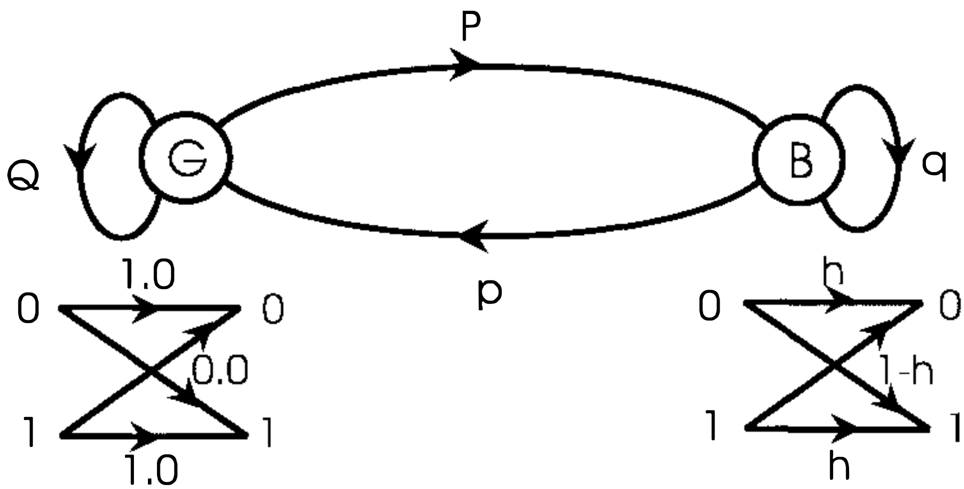

Figure 1. Link Statistical Bit Error Model.

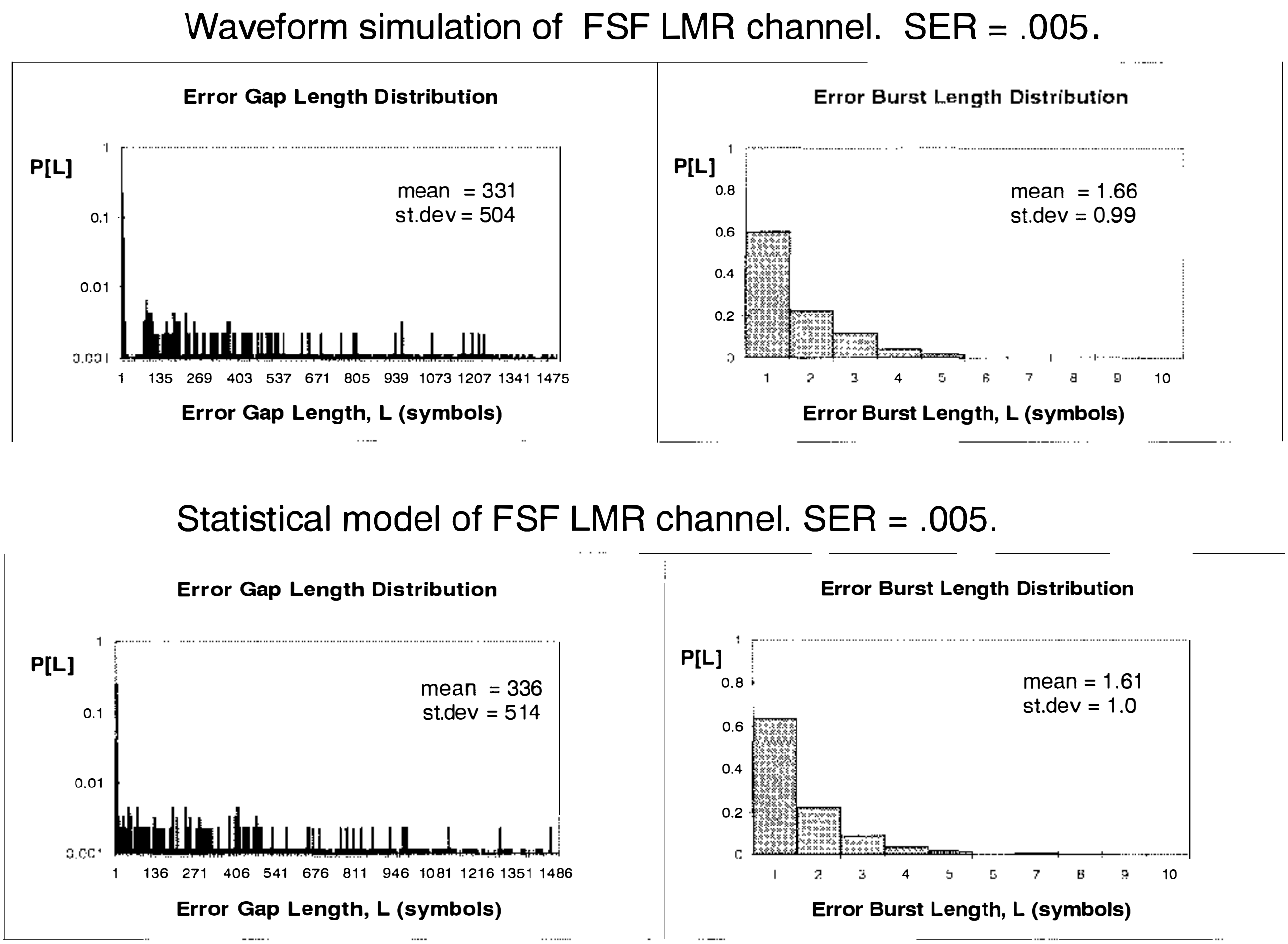

Figure 2. Comparison of Simulated and Modeled Distributions.

WIRELESS LINK SIMULATION AND PERFORMANCE PREDICTION

OUTPUTS

- Channel simulation (impulse response, noise, and interference) software modules.
- Validated system and channel simulation software modules.
- Predicted BER performance as a function of SNR and interference.
- Predicted speech quality as a function of BER, SNR, and interference.

Rapid development and deployment of wireless technology have stimulated the need for performance prediction of these systems before they are built, standardized, or deployed. ITS has been conducting research in wireless systems for many years. Past efforts have included radio channel propagation and impulse response measurement and modeling, software simulation of the channel for system performance prediction, hardware simulation of the channel for system hardware testing, and network performance prediction. Recent efforts have predicted link performance through software simulations of the system and channel for a variety of channels, modems, processing techniques, and sources. Channels include ionospheric, outdoor macrocell and microcell, and indoor microcell environments. Processing techniques such as encryption, equalization, and channel coding have been used.

ITS has investigated the effects of multipath fading, noise sources, and cochannel/jammer interference on performance of landmobile radio (LMR), wireless private branch exchange, wireless local area networks, and ionospheric high frequency systems. Three types of channel distortion have been used in the simulations: time-varying multipath, additive noise, and cochannel interference. Sources employed include data, pulse-code modulated and voice-coded speech, FAX, images, and automatic link establishment signals. Performance is described by bit error ratio (BER), frame error ratio, eye diagrams, in-phase/quadrature diagrams, character error ratio, speech quality, and image quality.

Figures 1 and 2 illustrate the performance of an LMR system travelling through an urban canyon with a closing velocity of 60 mph while operating at a shared frequency of 900 MHz. A 4.8-kbps code-excited linear prediction (CELP) voice-coded speech source is transmitted by a frequency shift keying modem spread with a frequency hopper. Cochannel interference occurs on the shared frequency from a differential phase shift keying modem spread with direct sequence. Figure 1 depicts effects of spectral spreading and frequency selective fading in the channel. The amount of closure in the Receiver Eye Diagram demonstrates the confusion present at decision time.

Figure 2 shows how end-user speech quality performance can be predicted for wireless systems through software simulation by relating regions of speech quality to the system and channel operational parameters: BER, signal-to-noise ratio, and jammer-to-signal-ratio. Class 5 represents the best quality and class 1 is not intelligible.

Predicted performance of these systems is used to compare proposed wireless standards, determine design specifications, and select deployment parameters of military communications systems.

RECENT ITS PUBLICATION

Wireless Performance Prediction via Software Simulation (by Quincy and Achatz).

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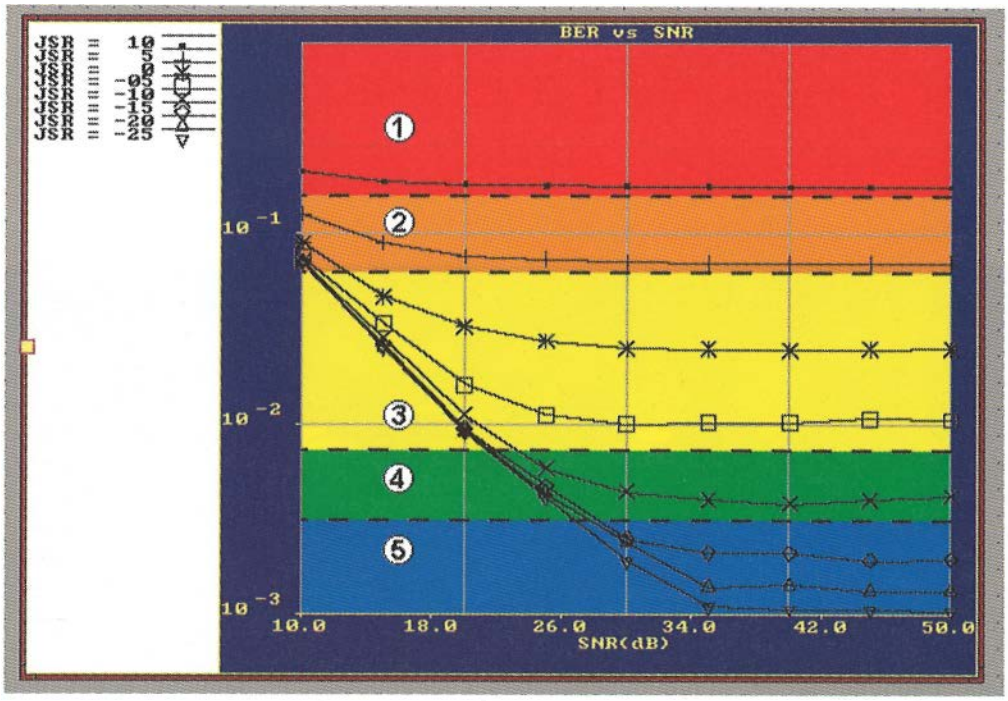


Figure 1. LMR Simulation Example: BFSK FHSS over a 3 Path Jakes Channel with BDPSK DSSS Interference [SNR = 40dB, JSR = -25dB].

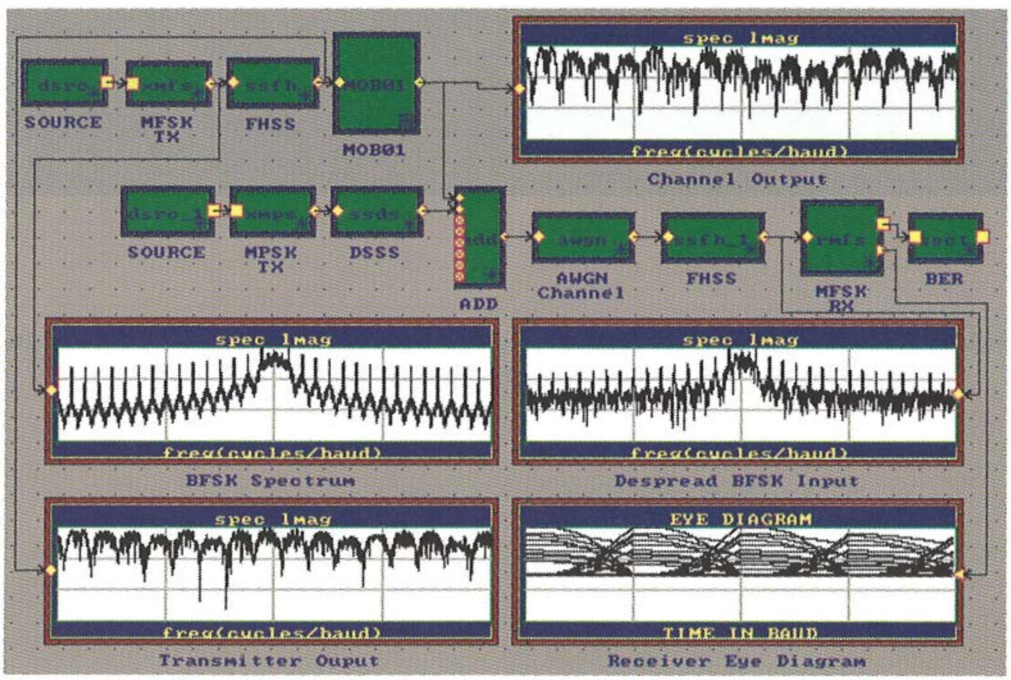
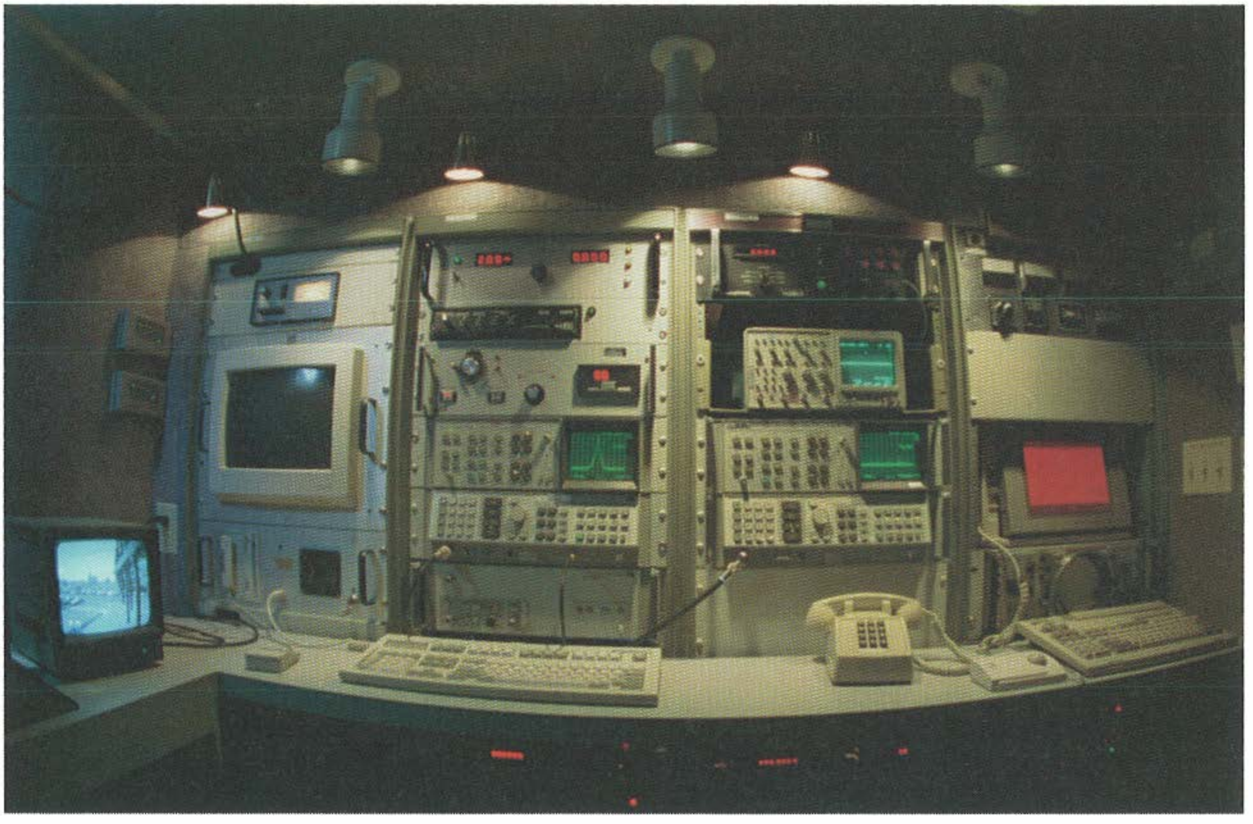


Figure 2. LMR Performance Relating CELP Voice-coded Speech Quality to System and Channel Parameters.



Inside of Radio Spectrum Measurement System. **See articles on pages 12, 14, and 16.**
Photograph by F. Sanders.

ITS TOOLS AND FACILITIES

ADVANCED COMMUNICATIONS SATELLITE TECHNOLOGY TEST FACILITY

The ITS Advanced Communications Technology Satellite (ACTS) test facility consists of an ACTS Earth Station (ES) and performance measurement equipment. ITS received the experimental Ka-band ES capable of a 1.8-Mbps data rate, integrated services digital network (ISDN) communications, and full mesh connectivity with every other ACTS ES through a Memorandum of Understanding with NASA. The performance measurement equipment includes UNIX workstations, an ISDN mini-switch, ISDN terminal adapters, satellite clocks, and modems. The ITS-supplied equipment will be used to characterize the digital communication service provided by ACTS from the user's perspective. In addition to ITS performing its own set of experiments, the facility is also supporting other ACTS experimenters, is open for demonstrations, and is available for Government, industry, and university use given approval by the NASA ACTS Experiment Office. To discuss experiment ideas using the ITS ACTS test facility, contact Marjorie L. Weibel at (303) 497-3967, e-mail mlw@its.bldrdoc.gov.

AUDIO COMPACT DISC FOR TESTING HF RADIO ALE INTEROPERABILITY

Federal Standard 1045A defines the sophisticated Automatic Link Establishment (ALE) protocols and techniques for adaptive HF radios. All ALE radios procured by the U.S. Government must perform the mandatory features defined in this standard. This assures that regardless of vendor, all ALE radios will interoperate successfully. Each radio system must be tested feature-by-feature to verify its interoperability. ITS has developed a digital audio compact disc (CD) for ALE radio interoperability testing that assures uniform, standardized conditions and repeatable results. This reference interpretation and implementation of FED-STD-1045A is available to all industry, Government agencies, and other ALE users. By connecting the headphone jack output of a CD player to the voice-activated input of an HF transceiver, the transceiver transmits a call played on the CD to an ALE radio under test. Thus, anyone using the ALE CD may test a radio against FED-STD-1045A. This approach to testing makes use of the digital compact disc player, a cost-effective, accurate technology for reproducing sounds. Measurements have indicated that frequencies and timing accuracy can be better than 10 ppm on good quality disc players. In addition, a CD is low cost and cannot be altered, thus assuring consistency among tests conducted by different ALE radio manufacturers and users.

The software, *alecall*, which created the Clean Tones HF ALE test CD is a valuable test tool as well. It can be used to create the ALE calls as sound files that can be played through a soundcard on a personal computer. The protocols are the input to the program and determine what call is produced. The protocol files, written in ASCII text, can aid users in interoperability testing because they specify the details of an ALE call, such as timing, correct addressing, expected response, and group call slot widths. An ALE call may be created with *alecall* and then used for real-time testing and analysis. As an enhancement to the audio CD concept for testing ALE radios, ITS completed the software with the addition of degraded, noisy, weak tones needed for performance testing. HF channel simulators are too expensive for many users. In FY 95 ITS plans to produce an additional set of CDs containing degraded tones based upon the Watterson propagation model developed at ITS. These CDs will augment the Clean Tones CD-01a by adding performance testing capability. In addition, using *alecall*, degradations caused by Gaussian noise, multipath, and fading can be added to any ALE call sound file. The user may specify signal-to-noise levels, bandwidth, and delay, and turn off and on the degraded conditions as desired. A user will be able to clearly define the parameters for radio performance testing.

AUDIO QUALITY LABORATORY

At the ITS Audio Quality Laboratory, studies are conducted to determine the impact of coding and transmission on perceived quality of audio signals. The laboratory provides facilities for the development and testing of objective audio quality assessment techniques. Laboratory equipment includes 486-based workstations equipped with 16-bit analog-to-digital and digital-to-analog converters. These workstations provide the interface between digital signal processing algorithms and high-quality analog audio signals. Mixers, amplifiers, headphones, microphones, and a computer-controlled digital audio tape recorder are also available.

Another important laboratory resource is the large database of subjective ratings of digital audio signals. This database is used as a benchmark to test proposed new objective audio quality assessment techniques. A second laboratory activity is the design and construction of specialized portable audio quality test instruments. These instruments are constructed by adding customized hardware and software to portable personal computers. The customized hardware provides interfaces to analog audio signals, while the software controls the interfaces and executes objective audio quality assessment algorithms. The Audio Quality Laboratory is interconnected with the Video Quality. and Digital Networks Laboratories. These connections enable the integrated testing of multimedia communication systems that transport audio, video, and data.

DIGITAL SAMPLING CHANNEL PROBE FOR PCS

ITS, in a joint effort with Telesis Technology Laboratories, Inc., has developed an innovative digital sampling channel probe for personal communication services measurements. The probe consists of a separate transmitter and receiver section. A patent is currently pending on this system. The probe is ideal for making outdoor impulse response measurements to characterize wideband propagation in the radio channel. The system currently has the capability of transmitting two different pseudorandom noise codes on different carrier frequencies, with different antenna polarizations, or with different antenna spacings. In the typical configuration, the null-to-null bandwidth of the probe is 20 MHz providing a delay resolution of 100 ns and a maximum measurable delay of 51 μs. The probe can be easily configured for wider bandwidths (finer time resolution) and different maximum delays.

A personal computer is used to control the dual-channel receiver. The dual-channel design allows different carrier frequencies, antenna spacings, or antenna polarizations to be implemented at the receiver as well as at the transmitter. The system has a processing gain of 27 dB with a receiver noise figure of approximately 8 dB. The received signal is converted to an intermediate frequency and then digitized. The in-phase and quadrature phase components of the impulse responses are computed by software. Recent improvements to the probe have included the addition of an absolute time measurement capability and the ability to measure Doppler spread. Future plans include expanding the probe to multiple channels for use in measurements helpful in analyzing the potential benefits of adaptive antenna arrays.

HF ALE RADIO NETWORK SIMULATIONS AND RADIO SIMULATORS

ITS is developing a series of HF radio automatic link establishment (ALE) network simulation products to aid in the development of HF ALE radios and associated networks. The purpose of these simulator products, supporting software, and network studies is to support Federal HF Radio Standards development, to conduct research on efficient ALE network configurations, designs, and operations, to study and predict radio network performance, and to study efficient methods of network simulation.

The simulator products being developed include an HF radio channel and modem simulator, a discrete event simulation model for HF ALE radio networks, and a network protocol simulator. The channel and modem simulator consists of software modules for testing ALE protocols, error correction, and linking protection techniques used in ALE radios. The discrete event simulation model is network simulation software used to determine the effects on network operation caused by periodic sounding to gain information on the propagation states of the available HF channels. The network protocol simulator is an implementation of digital signal processor hardware and software, running in a real-time mode, to simulate HF ALE radio network operation. Simulation studies using these products allow determination of the throughput and delay effects of advanced networking features such as sounding, polling, direct and indirect message routing, automatic message exchange, and store-and-forward message exchange. System users and administrators can use the results of these studies to chose the proper mix of newly-developed advanced network features and functions to achieve maximum channel efficiency.

Results of network simulation studies will also be useful to HF ALE radio users, standards developers, network designers, and radio manufacturers and vendors. Use of simulation studies of ALE radio networks are intended to reduce the over-the-air (OTA) tests required since OTA network testing may not always be practical, or cost-effective. The advantages of network simulation verses OTA testing is the reduction of resources needed to adequately gauge the effects of implementing new networking functions and features.

HF WIDEBAND CHANNEL SIMULATOR

ITS has developed a unique capability for simulating the channel conditions encountered on HF communication links in order to evaluate the performance of HF radios under a variety of repeatable, controllable conditions. The channel simulator employs state-of-the-art digital signal processing technology to employ new mathematical models of the propagation, noise, and interference environments. Unlike past HF channel simulators that are only valid over narrowband (several kHz bandwidth) channels, the new simulator is based on a fundamentally new approach that enables the simulation of wideband (on the order of 1 MHz bandwidth) as well as narrowband channels, both disturbed and nondisturbed. ITS personnel are in the process of developing a second HF channel simulator with greater capabilities, including wider bandwidth and the ability to simulate extremely disturbed ionospheric conditions.

INTEGRATED NETWORKS SIMULATION ENVIRONMENT

Computer-based modeling and simulation is a research tool that is rapidly growing in the field of telecommunications engineering. ITS maintains an environment for model development and communications network simulations. This system is currently hosted on two Silicon Graphics workstations. These computers are connected by an ethernet local area network to share resources. Each workstation has a complete software development environment. This includes the object-oriented OPtimized Network Engineering Tools (OPNET) program for developing, executing, debugging, and analyzing simulation models. Revision control tools allow creation of multiple versions of the same model with the addition or subtraction of features as needed. The capabilities of this system include: simulating ethernet and FDDI LANs, packet-switched networks, satellites, and other systems.

INTEGRATED NETWORKS TESTBED

Capabilities of this facility include integrated services digital network switching and emulation of broadband networks. Originally developed to provide validation of performance standards relating only to computer communications, the laboratory has evolved, keeping pace with the changes in the telecommunications industry. The most recent addition to the laboratory is the ability to pass live streams of digitized video through an emulated, real, or hybrid asynchronous transfer mode (ATM) network. The laboratory can provide essential information to assist in the development of the National Information Infrastructure (NII). In addition, when combined with capabilities of the Audio Quality Laboratory and the Video Quality Laboratory, it becomes an even more powerful tool. This complex of integrated laboratories puts ITS at the forefront of the development of the next generation of performance standards, those pertaining to multimedia communications. As the NII evolves, it will provide multimedia services, and there will be requirements to measure the performance of those services. This testbed will provide those measurement capabilities.

LABORATORY ATMOSPHERIC SIMULATOR

ITS has a unique atmospheric simulator facility to measure the radio refractive index of moist air. A computer-controlled environmental chamber, resonator, and millimeter-wave vector network analyzer provide highly accurate measurements of attenuation and phase delay in the frequency range of 10-220 GHz. The simulator permits the pressure to be varied over six orders of magnitude (0.001 to 103 millibars), the relative humidity to be varied between 0 and 100 percent, and the temperature to be varied between 270 and 320 Kelvins. The simulator provides a means of conducting millimeter-wave propagation experiments in a controlled environment that can represent atmospheric heights from the Earth's surface to 120 kilometers. This latter height provides a realistic basis for conducting experiments that are representative of satellite heights for most applications. This tool is available for use by private parties on a reimbursable basis.

LOCAL AREA NETWORK

ITS' local area network (LAN) allows the Institute to quickly respond to new programs and new technologies. This LAN interconnects every office and laboratory within ITS, and provides access to sponsors, research collaborators, and other agencies through wide area network (WAN) connections.

The LAN provides electronic mail, client-server computing, and peer-to-peer services for all ITS personnel, using TCP/IP and NFS applications. Currently, the LAN operates as an IEEE 802.3 10 Base-T ethernet. This ethernet supports over 160 heterogeneous computers including PCs, Macintoshes, and Hewlett-Packard, Sun Microsystems, Silicon Graphics, and Data General RISC workstations.

Over 45,000 feet of hybrid copper/optical fiber cabling integrates ITS' facilities in a physical star topology. Nearly 160 LAN wall outlets connect to one of two central wiring closets, which are interconnected with redundant fiber optic backbone cables. All outlets are capable of supporting 100-MHz data rates either via twisted-wire pair, or optical fiber. This arrangement allows easy reconfiguration of the network, and the delivery of new high-speed services to any part of the Institute as the requirement arises.

The combination of flexibility and available bandwidth allows ITS to extend its laboratory capabilities by interconnecting separate labs and equipment as needed for a particular research or test capability. For larger programs, a distributed testbed may be rapidly assembled.

Wide area connections to the Internet allow ITS personnel to exchange information with NTIA, NASA, the National Communications System, and other federal agencies, universities, and industry. If you require dial-up access, an account, or other information, please contact Darren Smith at (303) 497-3960, e-mail dsmith@its.bldrdoc.gov.

MICROWAVE LINE-OF-SIGHT CHANNEL SIMULATOR

ITS has developed this tool to simulate channel fading in a controlled environment in order to evaluate the performance of different microwave radios under identical conditions. This simulator was developed to perform evaluations for the Department of Defense; however, it could also be used for testing microwave radios used in the private sector.

MICROWAVE LINE-OF-SIGHT AND TROPOSCATTER CHANNEL PROBES

ITS uses these instruments for measuring the amount of multipath on either line-of-sight or troposcatter communication links. Multipath is the result of reflections, scattering, or atmospheric refraction of the signal as it propagates from the transmitter to the receiver. It causes a deterioration of radio performance. Channel probes are used to measure the amount of multipath, which is a dynamically changing quantity, during the period in which radio performance is being measured. This permits a correlation of the amount of multipath with the performance level of the radio.

MOBILE MILLIMETER-WAVE MEASUREMENT FACILITY

ITS has a highly sophisticated, fully computerized, 10- to 100-GHz channel probe for determining the performance of potential communication paths. Each terminal (transmit and receive) can be fixed or mounted on a van, which provides a means to perform path measurements in environments ranging from urban to isolated locations. Measurements and analysis from remote terminals (via wire or telephone) can be conducted to determine occurrence of signal fades and identify fade mechanisms (such as rain attenuation, multipath phase interference, antenna beam decoupling, and ray defocusing), and channel distortion across a 1.5-GHz bandwidth. Instrumentation to measure meteorological parameters such as rain rate, refractive index, and water vapor content is also available for simultaneous observation. This facility is available for use by private parties on a reimbursable basis.

RADIO SPECTRUM MEASUREMENT SYSTEM

The Radio Spectrum Measurement System (RSMS) is an ITS asset which makes available broadband (0-18 GHz) measurement in a self-contained vehicle. The RSMS is used to support Federal spectrum management tasks, and as such, is used by NTIA, other agencies, and private industry on a cost-reimbursed basis. The system capabilities are defined by a unique complement of hardware, software, and operations personnel.

The RSMS consists of a pair of 0-to 18-GHz measurement systems. The systems include frequency domain, time domain, and modulation domain analyzers. Key to the system's usefulness are preselected, low noise RF front ends. The systems can be operated in fully automatic (computer-controlled), semi-automatic, and fully manual modes. Control and analysis software has been written by ITS for spectrum management tasks, including specialized algorithms for acquisition of emitter (e.g., radar and LMR) signatures. Remote control via telephone lines is possible. The entire system is mounted in a C-130 transportable vehicle, along with a generator, air conditioning, and a pair of 30-foot telescoping masts.

Most important is the expertise of the operations personnel who use the RSMS to make measurements. A common problem with highly-automated and sophisticated measurement systems is an inability to determine the quality of a measurement while it is in progress. RSMS personnel bring decades of experience determining measurements required to fulfill a goal, setting up a measurement configuration that will successfully acquire those measurements, and assessing the quality of the measurements as they are conducted.

THE TABLE MOUNTAIN RADIO QUIET ZONE

This unique facility (one of only two in the nation) is controlled by public law to keep the lowest possible levels of unwanted radio frequency energy from impinging on the area. This allows research concerned with low signal levels (such as from deep space, extraterrestrial low-signal satellites, or very sensitive receiver techniques) to be conducted without the ever-present interference found in most areas of the nation. As the use of electronic systems (garage door openers, computers, citizen band radios, cellular telephones, arc welders, and appliances such as microwave oven), the number of radio and TV stations, and new uses for the radio frequency spectrum increases, the average level of electromagnetic energy across the spectrum will increase. This is important to companies involved in developing sensitive radio receivers and signal processing equipment, since the equipment is often saturated by the background signal level. The Table Mountain facility is available for use by private parties on a reimbursable basis.

TELECOMMUNICATIONS ANALYSIS SERVICES

These services provide the latest engineering models and research data developed by ITS to industry and other Government agencies. TA Services is interactive and computer-based, and is designed to be both user-friendly and efficient. It offers a broad range of programs that allow the user to design or analyze the performance of telecommunication systems. The services include terrestrial, ionospheric, and space systems and built-in databases that allow the consideration of terrain, atmospheric, and precipitation effects on a system under study. TA Services has been used in solving interference problems, designing cellular radio systems, and reviewing Federal Communications Commission applications for licenses.

VIDEO QUALITY LABORATORY

The ITS Video Quality Laboratory is used to develop and test automated techniques for assessing the quality of video and image data. This laboratory consists of a distributed workstation for implementing and testing a large set of video and image parameters, a real-time PC-based system that can perform video quality measurements in the field, and a viewing room (built to ITU-R specifications) that is used to view and subjectively grade video data. The viewing room provides a means for validating the objective video and image parameters from the computer-based systems. Since most of the newer video systems being used by the telecommunications industry are digital, the video quality laboratory hardware and software have been specifically designed to address this difficult measurement problem. Integration of the ITS Video Quality Laboratory with the ITS Audio Quality Laboratory and the Integrated Networks Testbed enables ITS to test multimedia performance.

Laboratory hardware consists of an ensemble of broadcast quality cameras, video recorders and players, image capture/display equipment, image processing workstations, digital video systems, and video test equipment. Computer hardware includes 486-based systems with broadcast quality (756x486 pixel) frame capture/display capability with real-time image .processing boards, two high-speed RISC workstations with high resolution monitors (1280x1024 pixels), a high-speed RISC server, over 3 GB of hard disk space for storing images, and a 1.3 GB tape drive. A high resolution color printer is used to obtain video prints or transparencies of processed imagery. Video equipment includes a broadcast quality camera, three monitors, a Betacam SP video recorder and player, VHS and S-VHS video cassette recorders, video format converters, a wideband video switcher, a programmable video signal generator, a video waveform monitor, an NTSC vectorscope, and a high-speed digital oscilloscope. Video teleconferencing coders/ decoders are used to generate distorted video teleconferencing data for study.

WIRELESS INTEROPERABILITY TESTBED

The ITS Interoperability Test Facility (ITF) was developed in FY 89-90 to support ITS' work for the National Communications System (NCS). During FY 91-93, the ITF was further enhanced with the capability to test additional wireless systems. The interoperability testing capability focuses on the requirements of national security/emergency preparedness.

The testbed simulates, models, and tests complex wireless systems. This includes testing of systems that use robust transmission algorithms such as code combining, Golay, and other forward-error correction codes. Impetus has been placed on error-free transfer of information because of the requirement to transfer images and other graphics by wireless methods. Specific requirements that use HF radio to transfer images have been tested at the ITF.

In recent testing, modems that employ simple, cost-effective protocols such as PACTOR, AMTOR, ARTOR, SITOR, CLOVER II, ALE, and G-TOR have been compared. Proof-of-concept testing has also been conducted for more robust, high-speed systems such as the proposed Federal Standard-1052 Data Link Protocol.

WIRELESS LINK SIMULATION AND PERFORMANCE PREDICTION LABORATORY

The ITS laboratory simulates wireless system and channel software for performance prediction with data, speech, vocoded speech, FAX, and image sources. ITS specializes in end-to-end results by performing channel characterization measurements, modeling the measurements, imbedding the models in simulation software, and predicting the system performance via simulation. Typically, predicted speech and image quality are determined as a function of signal-to-noise ratio, jammer-to-signal ratio, and bit error ratio for a selected radio system and channel. These results are useful in determining predicted performance of proposed wireless standards and are used to determine design specifications for these systems.

Laboratory hardware consists of a RISC workstation, a Pentium, several 486 workstations, and a color printer for performing simulations, predicting performance, and displaying results. An audio cassette, S-VHS recorder and players, and an S-VHS TV monitor are available for storing and demonstrating speech, images, and video. A programmable 6-MHz bandwidth hardware channel simulator is also available for real-time testing of transmitters and receivers using channel measurements.

ITS PROJECTS-FY 1994

FEDERAL EMERGENCY MANAGEMENT AGENCY

Assessment of Potential Personnel Hazards Due to High-frequency Radio Antenna Systems — Chris Redding (497-3104). Analyze field strengths of the electric field vector produced by various high frequency antennas used by FEMA.

FEDERAL HIGHWAY ADMINISTRATION

Analysis of Global Positioning Systems (GPS) — Robert O. DeBolt (497-5324). Examine current augmented GPS requirements and needs of aviation, marine, and land users and evaluate the options for meeting these needs. Recommend the GPS augmentations that would satisfy civil and commercial requirements without compromising national security. See article on page 48.

Electromagnetic Compatibility of the Intelligent Vehicle Highway System (IVHS) — Nicholas DeMinco (497-3660). Provide support to the IVHS program as it applies advanced technology for safety and throughput. Develop communication systems that will provide information to travelers, their vehicles, and the infrastructure. Support development of standards. Identify spectrum issues as they relate to electromagnetic compatibility of the IVHS. See article on page 40.

FEDERAL RAILROAD ADMINISTRATION

Railroad Telecommunications Study — Eldon J. Haakinson (497-5304). Review and comment on the ability of a new railroad telecommunications system to provide safety features desired by the Federal Railroad Administration. See article on page 42.

GENERAL ELECTRIC

Emission Measurements of an RF-driven Lighting Device — Frank H. Sanders (497-5727). Measure radio emissions of a newly-developed lighting device. The measurements will characterize the RF emissions produced by the device; these data will be used by the Federal Communications Commission for introduction of such devices into the commercial market.

McLEAN RESEARCH

HF Support — Greg R. Hand (497-3375). Provide consultation and advisory services regarding radio propagation.

MOTOROLA

Impulse Response Measurements — Peter B. Papazian (497-5369). Provide fundamental knowledge for radio propagation at 841 MHz through collection and analysis of mobile impulse response measurements within existing cell sites in Hong Kong. See article on page 68.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Multipath Measurements in the Land Mobile Satellite Radio Channel — John J. Lemmon (497-3414). Support the development of a GPS Multipath Measurement System for measuring multipath propagation in the land mobile satellite radio channel.

NATIONAL COMMUNICATIONS SYSTEM

Compact Disc for Interoperability Testing of HF Automatic Link Establishment (ALE) Radios — David R. Wortendyke (497-5241). Develop an audio compact disc (CD) that will provide a precise duplication of the HF radio ALE tones that represent standardized calls used for communications between ALE-equipped HF radios. The information on the CD will be copyrighted to protect the integrity of the information and will ensure that users have a good quality copy of the CD. The software to produce the ALE tones with a PC-based sound card is available free of charge on the Internet. See article on page 62.

Development of a Wireless Radio Protocol Simulator — Larry M. Brewster (497-5953). Through simulation, test the features and functions that define networking and message delivery. These functions and features are part of proposed Federal Standard 1046/1A, 2, 3 and Federal Standard 1047/1, 2. A laboratory method to test these multinode operational functions could eliminate the need for purchase and deployment of expensive radios at multiple nodes to perform the tests.

Enhanced HF Radio Interoperability Test Facility — David F. Peach (497-5309). Enhance the capabilities of the existing HF Radio Interoperability Test Facility to include the ability to perform interoperability testing of VHF/UHF/SHF single-channel radios, meteor-burst radios, and satellite and fiber optic transmission systems.

Foreign Dependence Information Assessment — David F. Peach (497-5309). Determine U.S. dependence on foreign sources for telecommunications systems and components that could affect national security/ emergency preparedness telecommunications within the U.S. The work requires identification of system and component dependencies and identification of a mechanism to monitor ongoing and long-term assessment of foreign dependence in telecommunications. See article on page 50.

HF Packet Radio Protocol Assessment — David R. Wortendyke (497-5241). Test performance of several protocols used in inexpensive packet modems. These tests were conducted using a laboratory channel simulator with repeatable noise, multipath, and fading conditions for each protocol.

Interoperability Standards for Land Mobile Radio — William J. Pomper (497-3730). Assist NCS in developing interoperability standards for the next generation of digital land mobile radios, particularly in the area of security. This information will be used for radios and standards for public safety applications.

NCS Integrated Voice/Video/Data Performance Measurement — David J. Atkinson (497-5281). Provide expert technical support for integrated voice/ video/ data measurement and standardization.

NCS Voice Quality Interoperability Standards — Stephen D. Voran (497-3839). Provide expert technical support for voice communications performance measurement and standardization.

Performance Testing of HF Automatic Link Establishment (ALE) Radios — David R. Wortendyke (497-5241). Develop software to produce degraded baseband ALE modem tones for testing of HF ALE radios. These tones will be included on a compact disc (CD) that can be used for interoperability and performance testing of HF radios. These CDs will be made available to users and providers of HF radios. See article on page 62.

Research and Development/Operation and Maintenance Engineering Services — David F. Peach (497-5309) and A. Glenn Hanson (497-5449). Provide technical support to NCS on performance and interoperation of Government telecommunication assets for national security/emergency preparedness purposes.

Revision of Federal Standard 1037B, Glossary of Telecommunication Terms — A. Glenn Hanson (497-5449). Provide expert technical support to NCS in revising this standard. This document provides Federal departments and agencies a comprehensive source of definitions of terms used in telecommunications and directly related fields used by international, and U.S. Government telecommunications specialists. See article on page 30.

Test and Assessment of HF Radio Antennas — Nathaniel McMillian (497-5750). Test several commonly used and available HF radio antennas in a controlled environment to determine performance of these antennas under similar conditions. This information is useful to Government agencies and others that use HF radios for communication.

Test of Concepts and Prototypes for Possible Inclusion in Proposed Federal Standard 1049, HF Radio Automatic Operations in Stressed Environments — Chris Redding (497-3104). Evaluate concepts and prototypes and perform appropriate testing to determine performance and functional interoperability capability.

NATIONAL INSTITUTE FOR STANDARDS AND TECHNOLOGY

Collaborative Planning for the Advanced Communications Technology Satellite (ACTS) — William A. Kissick (497-7410). Develop a collaborative proposal with COMSAT, MITRE, and NIST to assemble a three-terminal satellite network using ACTS earth stations. This network will be used to determine the performance of several applications used over ACTS. See article on page 60.

Timing and Synchronization of Synchronous Optical Network (SONET) via Asynchronous Transfer Mode (ATM) — Randall S. Bloomfield (497-5489). Provide up-to-date technical information on the design and operation of SONET and ATM systems. Identify and describe timing and synchronization problems, both current and anticipated, in the implementation of this equipment in networks.

Wireless Communications Benchmarking Research — Kenneth C. Allen (497-5474). Cooperatively initiate, with NIST, the development of a National Wireless Performance Benchmarking Program. This program provides U.S. industry, service providers, and users of wireless communications with performance measurement tools and information to promote the rapid development and deployment of wireless communications.

NATIONAL SECURITY AGENCY

Impact of New Communications Technologies — Timothy H. Cole (497-7578). Assess the impact that emerging and future telecommunications technologies will have on information systems security.

NSA Consulting — A. Donald Spaulding (497-5201). Provide consultation and advisory services in areas such as optimum system design and performance determination, detection algorithms, and interference modeling.

Technical Support for Defining and Designing the Global Grid — Timothy H. Cole (497-7578). Analyze the network management and integrated network interface technology of the Global Grid plan. Identify security issues and security solution requirements.

NATIONAL TELECOMMUNICATIONS AND INFORMATION ADMINISTRATION

Advanced Satellite Communication Technology Studies — Marjorie L. Weibel (497-3967). Conduct experiments, using the Advanced Communications Technology Satellite, to characterize system performance for the next generation of communications satellites that will use scanning, spot-beam antennas, and onboard signal processing. Investigate appropriate roles for advanced communications satellites in providing Broadband Integrated Services Digital Networks. See article on page 60.

Assessment of Digital Imagery Transmission over HF Radio Circuits — Paul C. Smith (497-3677) and Chris Behm (497-3640). Evaluate hardware and software to determine optimum settings for Tactical Communications Protocol #2 (TACO2). TACO2 is a unique addressing protocol developed for U.S. Government and recommended for use with the National Imagery Transmission Format Standard.

Broadband Networks — William R. Hughes (497-3728). Build the infrastructure necessary for ITS to take a leading role in developing a broadband research community by expanding and enhancing the Institute's capabilities for broadband networks performance measurement.

Broadband Wireless Standards — Eldon J. Haakinson (497-5304). Provide leadership and technical contributions to national and international wireless standards development that enhance domestic competitiveness, improve foreign trade opportunities, and facilitate more efficient use of the radio spectrum. Active support is provided in the International Telecommunications Union-Radiocommunication Sector, the Joint Technical Committee (JTC) for PCS air interface standards, and the IEEE 802.11 Wireless Local Area Networks Standards Committee.

Broadband Radio Research — Peter B. Papazian (497-5369). Support the development of broadband radio technologies and applications, especially high-data-rate, digital communications. Measure and model millimeter-wave propagation. Measure and model broadband indoor propagation and support the development of wireless local area network standards.

Broadcasting and Related Propagation Studies — Bradley J. Ramsey (497-3165) and Eldon J. Haakinson (497-5304). Provide support to NTIA's Office of Policy Analysis and Development for high definition television studies. This program develops fundamental data and more accurate modeling of radio propagation that will lead to improved implementation of advanced broadcasting techniques including high definition television.

Spectrum Technology Research — Jeffrey A. Wepman (497-3644). Develop knowledge of the impact of advanced radio technologies on spectrum use in support of changes in spectrum management and policy. In FY 94, digital sampling receiver technology was studied to assist in the determination of necessary changes in spectrum management to handle the future increase in the use of digital sampling receivers. A set of measurement techniques was also recommended to quantify spurious emission levels from radars operating in the 3- and 5-GHz bands.

Digital Networks Performance — David J. Atkinson (497-5281). Promulgate and demonstrate compatible Federal and American National Standards and international standards for specifying and measuring data communication performance. Provide emphasis on the application of these standards to, or integration with, voice and video performance in Integrated Services Digital Networks. See article on page 28.

International Standards — Neal B. Seitz (497-3106). Provide leadership to T1 and U.S. International Telecommunication Union-Telecommunication Sector (ITU-T) preparatory committees and international work groups. Prepare technical contributions to advance ITU-T standards development and draft recommendations on broadband digital networks. See article on page 22.

National Information Infrastructure (NII) and Personal Communication Services (PCS) Research — James A. Hoffmeyer (497-3140) and David F. Peach (497-5309). Develop plans for design, implementation, and operation of an NII multimedia testbed, including PCS testing. Participate in related standards activities. See article on page 44.

Objective Audio Quality Research and Standards Development — Stephen D. Voran (497-3839). Develop perception-based objective audio quality assessment techniques and standards contributions in support of advanced audio coding and Integrated Services Digital Network standards within T1 and the International Telecommunication Union-Telecommunication Sector. See article on page 24.

Operational and Technical Analysis of Broadband Antennas — Paul C. Smith (497-3677). Evaluate the effectiveness of several broadband antennas for use by Federal agencies for portable, tactical, or emergency use.

Personal Communication Services (PCS) Radio Systems — Michael G. Laflin (497-3506). Provide support for the development of PCS radio technology through measurements, modeling, and simulation of the radio channel; analyze spectrum issues including spectrum sharing, interference, and access methods; and provide technical support for national and international standards development. See article on page 32.

Radio Spectrum Measurement System (RSMS) Engineering Enhancements — Frank H. Sanders (497-5727). Enhance the measurement capabilities of the RSMS (both the vehicle and suitcase-deployable system) as needed to provide improved measurement data. See article on page 18.

Radio Spectrum Measurement System (RSMS) Operations — Frank H. Sanders (497-5727). Measure spectrum use, and other technical parameters of radio systems, needed for frequency management planning activities. See article on page 12.

Satellites and Integrated Services Digital Networks (ISDNs) — Raymond D. Jennings (497-3233). Perform research to determine the role of advanced communications satellite systems in providing broadband ISDNs. Interface and management standards for networks composed of both advanced terrestrial and satellite resources (hybrid networks) are factors of particular interest in this research. See article on page 60.

Spectrum Efficiency Studies — Robert J. Matheson (497-3293). Develop the general principles for efficient use and management of the spectrum, and resolve specific current issues related to spectrum efficiency.

Spectrum Engineering Models — Robert J. Matheson (497-3293). Develop and implement spectrum engineering models necessary to effectively manage the Government's use of the radio spectrum.

Spectrum Resource Assessments — Jeffrey A. Wepman (497-3644). Assess spectrum utilization, identify existing or potential compatibility problems among Federal telecommunications systems, provide recommendations for resolving any compatibility conflicts in the use of the frequency spectrum, and recommend changes to improve spectrum management procedures.

Technical Assistance for the Pan-Pacific Education and Communications Experiment by Satellite (PEACESAT) — Raymond D. Jennings (497-3233). Provide technical assistance to the PEACESAT program in the application of satellite communications and network technology. PEACESAT is administered by the University of Hawaii to provide international distance education, research, telemedicine, emergency management, and economic development communications to 40 locations in 21 countries throughout the Pacific Basin using a retired Geostationary Operational Environmental Satellite (GOES). See article on page 60.

Telecommunications Analysis Services (TA Services) — Robert O. DeBolt (497-5324). Make available to the public, through user-friendly computer programs, a large menu of engineering models, scientific and informative databases, and other useful communication tools.

Video Quality Standards — Stephen Wolf (497-3771). Develop video quality assessment techniques and standards contributions in support of Integrated Services Digital Network (ISDN) standards within T1 and the International Telecommunication Union-Telecommunication Sector, focusing on applications in video teleconferencing, high definition television, and video communications over broadband ISDNs. See article on page 26.

Wideband HF Channel Simulator for the Extended Interoperability Test Facility (EITF) — Paul C. Smith (497-3677). Obtain and integrate an upgraded, portable wideband HF channel simulator capability, based on the EITF model. The new wideband simulator will allow ETIF to test wideband HF and frequency hopping systems.

TELESIS TECHNOLOGIES LABORATORY, INC.

Impulse Response Measurements and Data Analysis in the 1850-1990 MHz Band — Jeffrey A. Wepman (497-3644). Perform impulse response measurements in various environments within the Boulder/Denver area, analyze the data, and prepare a report on the measurements and results. Custom build two digital sampling channel probes for delivery to TTL. See article on page 68.

Propagation Study for Local Multi-point Distribution Services (LMDS) — Roger A. Dalke (497-3109). Identify propagation factors that require further study before the performance of LMDS systems can be predicted. Provide a practical plan for obtaining the necessary measurements identified.

U.S. ARMY
Communications Electronics Command

HF Radio System Test Support — Patricia J. Longstaff (497-3568). Provide radio spectrum measurements to support field testing of an HF system development as an independent monitor and test evaluator.

Radio System Simulation and Performance Prediction — Edmund A. Quincy (497-5472). Software simulation of HF radio systems to predict performance for a variety of channel conditions, sources, modulations, and coding. See article on page 76.

U.S. ARMY
Foreign Science and Technology Center

Jammer Effectiveness Model — Nicholas DeMinco (497-3660). Develop a Jammer Effectiveness Model using a windows interface shell and ITM, GWAPA, and IONCAP propagation models. See article on page 58.

U.S. ARMY
Information Systems Engineering Command

HF Propagation Prediction Modeling — Larry R. Teters (497-5410). Assist in the study of analytic techniques for tactical operational use through HF propagation modeling.

U.S. ARMY - Reserves

Independent Testing Evaluation of the Reserve Component Automated System (RCAS) — Val J. Pietrasiewicz (497-5132). Establish a comprehensive testing evaluation program for RCAS contractor and technical testing. Independently evaluate testing methodology and results, and report on the findings. See article on page 56.

Technical Test of the Reserve Component Automated System (RCAS) — Richard E. Skerjanec (497-3157). Provide technical testing and evaluation during the development and fielding phases of the RCAS. The RCAS is an automated information system including computers, software, and networks connecting over 5000 sites to improve operational readiness of the Army National Guard and Army Reserves. See article on page 56.

U.S. ARMY
Yuma Information Systems Command

Yuma Remote System — Donald H. Layton (497-5496). Produce a radio monitoring system for direction finding and spectrum management for the U.S. Army at the Yuma Test Range. See article on page 18.

USDA FOREST SERVICE

Eastern Region Forests Telecommunications Planning — Wayne R. Rust (497-5572). Develop a long-range strategic telecommunications plan and short-range tactical plans for 15 National Forests in the Eastern Region of the United States. See article on page 42.

U.S. INFORMATION AGENCY

Consulting on the Ionospheric Communications Enhanced Profile Analysis and Circuit (ICEPAC) Prediction Program — Greg R. Hand (497-3375). Provide consultation and advisory services regarding the accuracy of the auroral absorption and ways of better implementing the sporadic E (foes) in the ICEPAC HF predictions program.

HF Propagation Model Studies — Gregory R. Hand (497-3375). Provide Voice of America (VOA), radio broadcaster for USIA, with a determination of the validity of broadcast service quality predictions using reception reports from VOA monitors. Provide modeling of advanced graphics displays to present VOA's propagation and monitoring results. Improve software to calculate the combined power distribution of all feasible propagation nodes.

U S WEST

Broadband Broadcast Millimeter-wave Measurement Study — Peter B. Papazian (497-5369). Perform broadband channel impulse response measurements in a suburban broadcast microcell over a spectrum centered at 30.3 GHz, and covering a bandwidth of 1 GHz. Process the measured data to indicate the expected performance of local multipoint distribution services. See article on page 66.

Building Penetration Measurements from Low-height Street Base Stations — Lynette H. Loew (497-3874). Study the penetration of microwave radiation into buildings from a transmitting height of 5 meters at three frequencies recommended for use for personal communication services.

Impulse Response Measurements — Peter B. Papazian (497-5369). Measure outdoor impulse responses for a new generation of digital cellular telephone system. Characterize wideband propagation at 881 MHz for personal communication services applications. This information will enable the sponsor to evaluation and improve proposed Code Division Multiple Access system performance. See article on page 66.

Impulse Response Measurements with Spatial Diversity — Lynette H. Loew (497-3874). Study impulse response measurements taken in urban and suburban environments to provide delay statistics, spatial diversity statistics, multipath power statistics, Doppler shifts, arrival angles, and the effects of directional antennas. See article on page 66.

ITS PUBLICATIONS-FY 1994

NTIA PUBLICATIONS

Linking Protection in Federal Standard 1045 HF Radios Using the Data Encryption Standard. NTIA Report 92-289, December 1993. C. Redding and W.J. Pomper.

A method of utilizing the Data Encryption Standard (DES) algorithm for linking protection in HF radios complying with Federal Standard 1045 is described. The unique DES encryption method, which permits a codebook type of encryption of 24-bit words, is explained in detail. Also discussed is the method used to integrate this encryption process with the Federal Standard 1045 automatic link establishment protocols. Processing speed requirements for the hardware and software used to implement this scheme are explained, and available DES devices that can support the described implementation are identified.

Land Mobile Spectrum Efficiency: A Plan for Federal Government Agencies to Use More Spectrum-Efficient Technology. NTIA Report 93-300, October. D.J. Cohen, P.C. Roosa, D.E. Kitzmiller, R.J. Matheson, and G.M. Patrick.

The National Telecommunications and Information Administration (NTIA) in the fall of 1992 was required by Congress to develop and commence implementation of a plan for Federal agencies to use wireless mobile technologies that are spectrum efficient and cost effective. In response, NTIA performed an analysis of the current Federal land mobile infrastructure with respect to spectrum efficiency and cost effectiveness. This report documents the analysis, its results and conclusions, and an implementation plan with recommended milestones.

The report includes a summary of Federal land mobile requirements and techniques such as Simplex, Trunking, Cellular, and Emerging Wireless Technologies. The benefits of rechannelization, trunking, and other technical methods to improve spectrum utilization are explained and their spectrum efficiency advantages are quantified. Methods to introduce cost effectiveness are also introduced. One of these methods is to exploit the economy of scope that exists, for example, if the cost of a single network is less than the cost of several individual networks. Policy and regulatory methods that NTIA could use to implement that plan presented in this report include Federal use of commercial vendor services (whenever feasible), and the use of shared systems among government agencies.

Measurement of Wind Profiler EMC Characteristics. NTIA Report 93-301, February. D. Law, F. Sanders, G. Patrick, M. Richmond.

This report provides the results of measurements that were conducted on a 404.37 MHz wind profiler located in Platteville, Colorado. These measurements included: radiated spectral (both high and low mode), radiated harmonic and subharmonic power measurements, characterization of the antenna frequency response, determination of the radiated antenna gain values near ground level, susceptibility of profiler performance to interference from selected emission waveforms, and the effects on a typical land mobile/amateur operation from wind profiler emissions. In addition, the report presents a detailed wind profiler system description including operations/functions, system hardware, digital signal processing, as well as an analytical estimation of the interference effects on profiler performance. The information contained within this report can serve as an aid in conducting electromagnetic compatibility (EMC) analysis to determine compatibility between wind profilers and other systems.

Foundations, Applications, and Assessment of Wavelets. NTIA Report 94-302, December. D.A. Sutherland Jr.

This report is an introduction to wavelet theory intended for the technical professional working in telecommunications. The basics of wavelet theory are presented with an emphasis on explanations of the principles and ideas involved rather than on the mathematical proofs. Differences between the wavelet transform and the windowed Fourier transform are pointed out. Wavelet applications to several issues important to telecommunications are presented.

Radio Spectrum Measurements of Individual Microwave Ovens. Volumes 1 & 2. NTIA Report 94-303, March. P. Gawthrop, F. Sanders, K. Nebbia, and J. Sell.

This report provides results of radio spectrum measurements of 13 individual microwave ovens performed at the National Telecommunications and Information Administration (NTIA) Institute for Telecommunication Sciences (ITS). Measurements include emission characteristics and time waveforms covering the frequency range 2300-2600 MHz and oven emission characteristics of harmonic frequency ranges up to the 7th harmonic. Test parameters were varied to identify their impact on test results. These parameter variations include such factors as cooking load, start temperature, oven orientation, and receiver bandwidth. Test procedures of the Federal Communications Commission (FCC), the International Special Committee on Radio Interference (CISPR), and additional procedures developed by NTIA and ITS are also discussed.

An Investigation of Federal Standard 1045 High-Frequency ALE Radio Performance in the Southern Trans-Auroral Zone. NTIA Report 94-304, January. P.C. Smith, R.T. Adair, and D.F. Peach.

This report presents the results of two weeks of bidirectional high-frequency radio path soundings in a trans-auroral environment between Christchurch, New Zealand, and the U.S. station, McMurdo (Black Island), Antarctica, during mid-January, 1992. The work was commissioned by the Naval Undersea Warfare Center, New London, CT, for the National Science Foundation. This investigation demonstrated the value of ALE adaptive radio systems as a real-time frequency management tool. Based on the results observed, the authors recommended that NSF consider the acquisition of a 1-kW ALE radio system to be used, primarily as an oblique ionospheric channel sounder, with their existing communications system. This addition would significantly improve NSF frequency management.

Test Plan for Experiments to Provide Preliminary Characterization of ACTS Performance. NTIA Technical Memorandum 94-161, February (Proc. IEEE 13th Ann. Internat. Conf. Computers and Commun., Phoenix, AZ April 12-15, 1994, pp. 478-484). M.L. Weibel.

In order for users to have a full understanding of how state-of-the-art satellite technology can improve the quality and reduce the costs of space-based communications, users must be given the system performance in terms they understand. For example, most users do not care how fast data can be routed through the satellite bus. The users want to know how fast they can send their data and thus the cost of sending a given amount of data. The experiments described in this test plan will provide a preliminary characterization of the Advanced Communications Technology Satellite (ACTS) from the user's perspective. The tests are designed, executed, and analyzed according to the American National Standards X3.102 and X3.141. The performance parameter values estimated in this preliminary characterization experiment will be used in the full characterization experiment to define failure/nonperformance outcome thresholds.

An Assessment of the U.S. Telecommunications Industry Dependence on Foreign Sources as it Impacts the U.S. Telecommunications Infrastructure. NTIA Report 94-305, April. Volumes I & 2. (National Communications System Technical Information Bulletin 94-3, April). D.F. Peach and M.D. Meister.

The National Communications System (NCS) is responsible for defining operational infrastructures and processes that could be detrimental to the provision of telecommunications equipment and services necessary to the National Security and Emergency Preparedness (NS/EP) needs of the Nation. To this end, the President's National Security Telecommunications Advisory Committee (NSTAC) studied the industry's dependence on various infrastructures within the United States to (1) identify possible impediments to effective telecommunications industry mobilization and (2) assist in the development of corrective actions to overcome any identified impediments. This study was published in 1989.

The information presented in the present report is a result of follow-on investigations that attempt to determine those components and materials used in the telecommunications equipment manufacturing process that are obtained from foreign sources. This report lists those components that are primarily procured from foreign sources. For example, plastic coated relays, printed circuit mounted transformers, and some types of semiconductors are a few of the components that represent vulnerabilities in the telecommunications switch (Class 5) manufacturing process. A result of this study is an analysis of the trends that are evident between the 1989 study results and results of this report. This report shows an increase in the components that are obtained almost exclusively from sources outside the U.S. and Canada. A contributing factor to the trend toward more foreign sourcing of components is the general trend toward a more global economy. In the final analysis, one must determine the components, and their sources, that could be the most detrimental to the mobilization of the Nation's telecommunications resources if these sources were no longer available. A determination of the sources that are most likely to be cut off is also important. An analysis of the circumstances that could result in the cut off of foreign sources is not a part of this report.

Building Penetration Loss Measurements at 900 MHz, 11.4 GHz, and 28.8 GHz. NTIA Report 94-306, May. K.C. Allen, N. DeMinco, J.R. Hoffman, Y. Lo, and P.B. Papazian.

The feasibility of using radio frequencies in the super high frequency (SHF) band (3-30 GHz) for Personal Communications Services (PCS) in buildings depends on the multipath within the structure and the amount of attenuation experienced by the electromagnetic waves passing through the structures. This study measured these effects to obtain a quantitative estimate of the attenuation magnitude. This magnitude can then be used for link margin analysis to determine if personal communications at SHF is practical.

A Software Simulator for High Frequency Radio Automatic Link Establishment. NTIA Technical Memorandum 94-162, May. E.E. Johnson, D.F. Peach, and R.T. Adair.

Automatic Link Establishment (ALE) technology automates the selection of channels and establishment of links among high-frequency (HF) radios. This report describes simulators for data-link-layer ALE functions. These simulator modules, in conjunction with simulators for fading channels and the Federal Standard ALE modem used over those channels, have been used to evaluate various concepts proposed for the HF standardization program.

U.S. Department of Agriculture Forest Service Eastern Region Strategic Telecommunication Plan 1994-2003. NTIA Report 94-307, May. W.R. Rust and E.J. Haakinson.

This report documents the development of a telecommunication strategy for 1994-2003 for the Eastern Region of the U.S. Department of Agriculture Forest Service. The Institute for Telecommunication Sciences (ITS) identified the telecommunication needs, assessed the existing telecommunication systems of the 15 National Forests in the Region, assessed internal and external factors that impact telecommunications planning, and assessed telecommunication technologies. Based on the foregoing, ITS developed a telecommunication strategy intended to ensure that the Eastern Region telecommunication systems and services support the mission of the organization in a reliable and cost-effective manner.

Impulse Response Measurements in the 1850-1990 MHz Band in Large Outdoor Cells. NTIA Report 94-309, June. J.A. Wepman, J.R. Hoffman, and L.H. Loew.

Mobile impulse response measurements were taken in the 1850-1990 MHz band in three different macrocellular (cell radii of 5 km) environments: flat rural, hilly rural, and urban high-rise. Spatial diversity with a 15-wavelength separation was employed by using a dual-channel receiver. All antennas were omnidirectional and vertically polarized. The data were analyzed to provide delay statistics; spatial diversity statistics; multipath power statistics; number of paths, path arrival time, and path power statistics; and correlation bandwidth statistics. The urban high-rise cell showed more multipath components (out to 4 or 5 μs in delay) than the rural cells. Very long delays (greater than 10 μs), while not seen often, were seen more frequently in the rural cells than in the urban high-rise cell. Parameters to help design a tapped delay model of the radio channel in the different environments are given.

High Frequency Radio Channel Error Model. NTIA Report 94-310, June. E.E. Johnson and D.F. Peach.

Simulation has been extensively employed to evaluate concepts included in the current generation of standards for automated high-frequency (HF) radio systems. As development proceeds from link-layer technology to network- and higher-layer technology, it is no longer necessary to devote great amounts of computer time to detailed simulation of the physical medium. Instead, the error behavior of the medium should be abstracted so that simulation resources can be concentrated on the phenomena of interest at these higher protocol layers.

In this report, a model of channel error behavior is derived that accurately captures the operation of the Automatic Link Establishment (ALE) modem operating over Gaussian noise and skywave channels. When this model is employed in place of a detailed simulation of the modem and channel, an overall simulation speedup of nearly two orders of magnitude results.

A Survey of Relative Spectrum Efficiency of Mobile Voice Communications Systems. NTIA Report 94-311, July. R.J. Matheson.

This paper provides definitions of spectrum efficiency for general communication systems, then simplifies the definitions so that the spectrum efficiency of several contemporary mobile radio systems can be easily compared. A variety of systems currently in use and proposed for near-term deployment are compared to analog FM dispatch radio. The calculations show a ratio of 1 million between the most efficient and least efficient of the systems considered. Based on these calculations, a comparison can be made between various technologies and their ability to deliver communications systems with a very high spectrum efficiency.

An Evaluation of the North American Train Control System. NTIA Report 94-312, July. E.J. Haakinson, W.R. Rust, and M.M. Garrity.

The railroad industry has proposed an advanced system for train control. This report presents an evaluation of the system development process, with particular emphasis on the data communication system that interconnects dispatch centers, locomotives, track maintenance vehicles, and wayside devices. The report describes the proposed train control system, establishes generic requirements for collision avoidance and telecommunication system development, and analyzes the system in light of the generic requirements.

Analysis of Electromagnetic Compatibility Between Radar Stations and 4-GHz Fixed-Satellite Earth Stations. NTIA Report 94-313, July. F.H. Sanders, R.L Hinkle, and B.J. Ramsey.

The susceptibility of 3700- to 4200-MHz fixed-satellite service earth stations to interference from radar signals, and the mechanisms by which such interference can occur, are examined. It is shown that interference can occur even if all currently applicable NTIA and FCC spectrum engineering requirements for radar emissions and earth station receiver systems are satisfied. It is further shown that while most interference problems can be resolved by installing appropriate radio frequency (RF) filtering on either the radar transmitter RF output or the earth station RF input, determinations of the system that requires filtering depends critically upon the interference coupling mechanism. Methods for determining the interference coupling mechanism are presented.

Initial Study of the Local Multipoint Distribution System Radio Channel. NTIA Report 94-315, August. P.B. Papazian, M. Roadifer, and G.A. Hufford.

A broadband millimeter wave study was completed to characterize the radio channel for Local Multipoint Distribution Systems in Boulder, Colorado. The study determined characteristics for proposed 20-MHz channels centered at 30.3 GHz using two transmitter heights in a suburban environment. Distribution of delay spread, correlation bandwidth, frequency selective fading, and scatter plots of signal loss are presented. The median signal loss for the 40-m transmitter height was 15 dB. Maximum delay spreads for this height were below 10 ns with a median value of less than 1 ns. Data was also collected to characterize a flat plate reflector proposed for use at 28.8 GHz. Cross cell interference and signal diffraction measurements were also made.

High Frequency Radio Channel and Modem Simulator. NTIA Technical Memorandum 94-163, August. E.E. Johnson, D.F. Peach, and R.T. Adair.

Automatic link establishment (ALE) technology automates the selection of channels and establishment of links among high-frequency (HF) radios. This report describes software that simulates fading channels and the Federal Standard ALE modem used over those channels. These simulator modules, in conjunction with simulators for data-link-layer ALE functions, have been used to evaluate various concepts proposed for the HF radio standardization program.

Orthogonal Frequency Division Multiplexing: An Application to High Definition Television. NTIA Report 94-316, August. G.A. Hufford.

"Orthogonal Frequency Division Multiplexing" is an interesting system architecture for high-data-rate transmission that has been receiving renewed attention. This report is a discussion of how it works and of how it might be used to carry High Definition Television. The principle tool is a computer simulation that allows us to look at many aspects of an OFDM system. It is concluded that the claims for the system largely hold up, and that its use might simplify many technical problems for HDTV.

OTHER PUBLICATIONS

Hybrid Digital Networks Using High-speed Optical Fiber and Advanced Satellite Systems, Proc. IEEE Military Commun. Conf., Boston, October 11-14, 1993, pp. 223-228. R.D. Jennings.

The Global Grid will be a hybrid, digital network with transmission provided by a combination of fiber-optic cables and radio links, many of which will be geosynchronous satellite links. This hybrid network will be an extremely complex environment that must be transparent to users. The technology for achieving this transparent interoperation has become identified as satellite/terrestrial network interface technology. This paper expands the discussion (begun at MILCOM '92) of important issues that pertain to transparent interoperation of the satellite and fiber-optic components. In particular, perspective to the concept of a hybrid network is presented by discussing infrastructure penetration and communications capacity for each transmission technology. Then, discussion of the diversity that exists in defining digital network hierarchies is presented. Finally, there is discussion of the protocols (and standards) that control how the many services offered by these networks are provided and may be utilized.

Satellite/Terrestrial Network Interface Technology, A Collection of Technical Papers, 15th AIAA Internat. Commun., Satellite Conf., San Diego, CA, February 23-March 3, 1994, pp. 129-136. R.D. Jennings.

The technology used to interface satellite- and terrestrial-based networks is in many respects more of an applications technology than one derived from basic science. Consequently, interface technology is more closely associated with the commercialization of communication satellite technology, i.e., the expansion of networks and offered services, than with the fundamental aspects of communication satellite technology. As such, its development is usually promoted and conducted by organizations different from those doing communication satellite R&D. Use of interface technology also is often critically dependent on national and international policies pertaining to telecommunications services.

Generally speaking, in both Europe and Japan, as in the United States, there has been limited interest in satellite/terrestrial interface technology. The panel members believe that they did not miss significant work in this area. Rather, planning for integrated networks, which would be the basis for funding such work, is seriously lacking world-wide.

PTTs are generally not interested in satellite/terrestrial network technology because they view wideband, fiber-optics networks as the major player, with satellite-based services being useful primarily in their absence. Examples are the extension of satellite-based services into numerous areas of eastern Europe and the use of satellites as backup for terrestrial services in the event of cable failures or in disaster situations.

There are, however, a few exceptions in Europe and Japan. In Europe, for example, the ITALSAT experiments include efforts devoted to hybrid networks that supplement the terrestrial PSTN. In Japan, there is NTT's DYANET program. DYANET II provides common alternative routing through the CS-3 satellites for PSTN trunks extending to about 62 switching centers, some in remote parts of the Japanese archipelago, with a capacity of more than 6,000 equivalent voice circuits. It also provides access for a limited number of ISDN users at remote sites in the ISDN network through Earth terminals at those sites connecting through terminals at terrestrial service access points.

Boundary Layer Wind Estimations with a UHF Doppler/Interferometric Wind Profiler, Atmospheric Radiation Measurement (ARM) Team Meeting, Charleston, SC, Feb 28-Mar 3, 1994. C.L. Holloway, D. Parsons, J. Van Baelen, and S. Copeland.

Spaced antenna (SA) systems have been used for some time to estimate the 3-D wind vectors in the atmosphere. The analysis of signals from these multiple receiver systems can be carried out in either the lag-time domain (correlation analysis) or the frequency domain (spectral analysis, sometimes referred to as Interferometry). The National Center for Atmospheric Research (NCAR) has developed a 915 MHz Doppler/Interferometric boundary layer profiler. In this presentation, we will present preliminary results from a June 1993 field project in Oklahoma. We will also show comparisons of these results to both the Doppler Beam Swinging (DBS) technique and to rawinsonde measurements.

A Simple Technique for Assessing HF Automatic Link Establishment Radio Interoperability, Proc. RF EXPO West Conf., San Jose, CA, March 1994. T. Young, D. Wortendyke, and C. Riddle.

Automatic Link Establishment (ALE) is a cornerstone in the growing trend of automation and ease in operation of high-frequency (HF) radios. The Federal Standard FED-STD-1045, the first in the family of automated and adaptive HF radio standards, together with Military Standard MIL-STD-188-141A, defines minimum features required in an ALE radio procured by a U.S. Government agency. The goal of the U.S. Government is over-the-air interoperability for all agencies citing these standards in their procurement, regardless of which vendors win the contracts. The National Telecommunications and Information Administration, Institute for Telecommunication Sciences (NTIA/ITS) has conducted performance and interoperability tests on HF ALE radios. This testing typically has been a costly and time-consuming process. In an effort to simplify performance and interoperability testing, NTIA/ITS has responded to an HF Industry Association (HFIA) request for a "Standard" test tape by producing the first audio compact disc (CD) that implements standard reference tones. The tones on the CD encode key specific functions of the Government standards. In addition, a companion floppy computer disk provides listings of the protocols used in generating the CD. The product was provided free of charge in November, 1993 to all members of the HFIA and interested U.S. Government agencies. The CD provides a common, easy-to-use, documented, and working implementation of the recently adopted FED-STD-1045A and FED-STD-1046/1 standards. The background and software method used to create the digital audio sound files for the CD are described. In addition, the potential of using this technique in related technologies is presented. Continuing efforts are described.

On the Application of Computational Electromagnetic Techniques to the Design of Chambers for EMC Compliance Testing, *Compliance Engineering*, March/April 1994, pp. 19-33. C.L. Holloway, P. McKenna, and R.F. German.

We describe two different, but mutually compatible, electromagnetic analysis techniques which can be applied to the design of semi-anechoic or fully anechoic chambers for EMC compliance testing/research. The first of these, referred to as the "absorber model," involves a method which allows one to replace a doubly periodic absorbing structure such as urethane pyramids or ferrite waffles by; layered 'effective' material properties. Using this method, it is possible to obtain the plane wave reflection loss of a sheet of material. This is extremely helpful in the efficient evaluation and optimization of absorber designs. The second method, referred to as the "chamber model," uses the layered 'effective' material properties in a full three dimensional solution of Maxwell's Equations. This allows one to obtain the chamber performance by mathematical modeling, as opposed to trial and error construction on a full-sized prototype. The computational technique used is a fully self-consistent total field solution for the electric and magnetic fields inside chambers, as opposed to ray tracing with images techniques. A further benefit of the full three-dimensional model is the ability to calculate the actual performance of the chamber when testing products.

Edge Shape Effects and Quasi-Closed Form Expressions for the Conductor Loss of Microstrip Lines, *Radio Science*, Vol. 29, No. 3, May-June 1994, pp. 539-559. C.L. Holloway and E.F. Kuester.

Much work has been done in the past to determine the conductor loss of microwave and millimeter-wave integrated circuits (MIMICs). However, much of this work is limited by constraints on the conductor thickness, skin depth, or the shape of the edge. In this paper, a technique will be presented that results virtually in a quasi-closed form expression for this loss in many cases. This expression will allow the calculation of the attenuation constant for a planar circuit for an arbitrarily shaped edge and any conductor thickness. The question of how different edge shapes affect the conductor loss will be addressed.

A Measure for the Quality of Anechoic Chambers, URSI Radio Science Meeting, Seattle, WA, June 19-24, 1994, p.174. R.R. Delyser and C.L. Holloway.

Return loss as a function of frequency and angle of incidence is typically studied to determine the quality of the absorbing material used in an anechoic chamber. This alone is not enough to determine the quality of an anechoic chamber, or to compare the quality of one anechoic chamber to another. While the information gained from return loss calculations and measurements as a function of angle is valuable, an overall measure of anechoic chamber effectiveness is necessary in order to compare different chamber designs. In this presentation, we discuss a new chamber quality factor based on the average of the reflection coefficient (or return loss) over all possible angles of incidence. We will show calculations of the reflection coefficients for typical materials used in these chambers. These calculations for the reflection coefficients are based on the models developed by Holloway and Kuester (EMC Symposium 1989 and EMKC Tran. 1994). We will also show calculations and comparisons of this chamber quality factor for anechoic chambers with different types of absorbing materials.

Spectrum Stretching: Adjusting to an Age of Plenty. *The IVHS Journal,* Vol 1(4), 1994, pp. 397-407. R.J. Matheson.

This paper shows-contrary to popular opinion-that spectrum crowding should decrease in the future. The causes of this decrease include the development of spectrum-efficient technologies like digital compression, the use of short-range systems, increased use of higher frequencies, changing Federal spectrum needs, and (especially) the rapid growth of optical fiber systems. Though the benefits from these factors will not be immediately available, it is possible to project large long term (10-15 years) gains in spectrum capacity. The implication for IVHS is that sufficient spectrum should be available for future IVHS requirements.

Wireless Performance Prediction via Software Simulation, Proc. 6th Internat. Conf. Wireless Commun. July 11-13, 1994, Vol 1, pp. 324-343. E.A. Quincy and R.J. Achatz.

The effects of multipath fading, noise sources, and jammer (cochannel) interference on performance are shown for example land mobile radio (LMR), wireless private branch exchange (WPBX), and ionospheric high frequency (HF) systems. The LMR system uses frequency-hopped spread spectrum (FHSS) binary frequency shift keying (BFSK), the WPBX system uses direct sequence spread spectrum (DSSS) binary differential phase shift keying (BDPSK), and the HF system uses BFSK with and without forward error correction (FEC). This paper shows how end-user speech quality performance can be predicted for wireless systems through software simulation by relating regions of speech quality to the system and channel operational parameters: bit-error-rate (BER), signal-to-noise ratio (SNR), and jammer-to-signal-ratio (JSR). These results demonstrate the dramatic robustness of vocoded speech to channel fading, noise, and jamming even though the vocoded speech is compressed 14:1.

Atmospheric Boundary Layer Investigations with a UHF Doppler/Interferometric Wind Profiler, 1994 Internat. Geoscience and Remote Sensing Symp. (IGARSS), Pasadena, CA, August 8-12,1994, pp. 2248-2450. J. Van Baelen, C.L. Holloway, and S.B. Copeland.

In this presentation, we will describe the prototype 915 MHz Doppler / Interferometric boundary layer profiler developed at the National Center for Atmospheric Research. The primary characteristic of the radar is its capability of simultaneous operation in a five beam Doppler beam swinging (DBS) mode and a radar Interferometry (RI) mode through the use of multiple receiving channels connected to subsets of its antenna. Radar interferometry allows to estimate the three-dimensional wind vector from a single beam direction while Doppler beam swinging combines the radial velocities measured in the multiple beam directions in order to derive the wind components.

We will present preliminary results from a June 1993 field project in Oklahoma. The wind profiles obtained with the DBS and RI techniques will then be compared. In particular we will assess the accuracy of the RI method and investigate whether it represents a reliable alternative to the traditional Doppler technique when the latter is adversely affected by a non-homogeneous or evolutive wind field.

UHF Profiling Radar Wind Estimation Techniques, 3rd Internat. Symp. Tropospheric Profiling: Needs and Technologies, Hamburg, Germany, August 30-September 2, 1994, pp. 280-282. C.L. Holloway, J. Van Baelen, and S.B. Copeland.

Multiple receiver wind estimation methods can be carried out in the time domain (correlation analysis) or in the frequency domain (interferometry). Cross-correlation or cross-spectral analysis will usually provide an over-estimate of the wind (the so called apparent wind) but correcting algorithms exist (full correlation analysis or full spectral analysis) in order to provide the so-called true wind estimation.

In this presentation, we will discuss the relative merits of the UHF implementation of these different algorithms and compare their results with simultaneous profiles obtained with the Doppler beam swinging technique and from collocated radio-sondes.

Also, we will consider the effect of antenna pair separation and orientation with respect to the wind on the derived measurements.

An Alternative Method for Inferring Winds from Spaced-Antenna Measurements, 3rd Internat. Symp. Tropospheric Profiling: Needs and Technologies, Hamburg, Germany, August 30-September 2,1994, pp. 277-279. R.J. Lataitis, S.F. Clifford, and C.L. Holloway.

The space-antenna technique for profiling horizontal winds typically relies on an elaborate procedure called the Full Correlation Analysis (FCA) to extract unbiased wind estimates. The technique is based on a calculation of the temporal cross-correlation function (CCF) generated from complex signals detected by a pair of receiving antennas. The FCA relates the position the peak of the CCF amplitude to the component V' of the wind along the antenna pair baseline.

We suggest that the slope-at-zero-lag (SZL) of the CCF amplitude is a more simple and direct measure of the wind. For many cases of interest, the SZL (normalized by the value of the CCF amplitude at zero lag) is proportional to the product of V' and a function that depends only on the antenna geometry, so that no FCA-type analysis is needed. Wind profiles obtained with the 915 MHz NCAR radar using multi-beam, FCA and SZL processing will be compared to rawinsonde measurements.

A Generalized Theoretical Analysis of Cross-Correlation and Spectra in Spaced-Antenna Wind Profilers, 3rd Internat. Symp. Tropospheric Profiling: Needs and Technologies, Hamburg, Germany, August 30-September 2, 1994, pp. 274-276. R.J. Doviak, C.L. Holloway, and R.J. Lataitis.

We develop a formulation which relates the properties of the refractive index irregularities (e.g., mean motion, anisotropy, random motion) to the cross-correlation of the complex scattered field detected by a pair of spaced receiving antennas.

Our formulation considers a pair of identical receiving antennas having diameters different that the transmitting one. The formulation also allows the receivers to be asymmetrically placed far from the transmitter so that displaced but overlapping scattering volumes, not considered in earlier work, is included.

The refractive index field is characterized in terms of the Kolmogorov spectrum of turbulence as well as a heuristic Gaussian model. Results obtained using a Gaussian model do not always agree with those obtained using a Kolmogorov spectrum, and suggest the Gaussian model can lead to an incorrect interpretation of experimental results.

Our solution also shows, for frozen irregularities translating at speed $V_{\sigma x}$ and receiving antenna diameters identical to the transmitting one, the magnitude of the cross-correlation function in the two dimensional space-lag (ΔX) time-lag (τ) domain has two equal amplitude peaks; one at $\Delta X=\tau=0$, and the other at $\tau=X_0/V_{\sigma x}$, where $\pm X_0$ is the symmetrical spacing of the pair of matched receivers. When the transmitting and receiving antenna diameters are mismatched, the peaks are not equal in amplitude.

In addition, we obtain a general expression for the cross-spectrum in terms of a spectral sampling function and an arbitrary spectrum for the refractive index. For most cases of practical interest, this expression reduces to a simple analytic form which allows physical interpretation of measurements.

UHF Doppler/Interferometric Profiler for Boundary Layer Studies: First Results, 3rd Internat. Symp. Tropospheric Profiling: Needs and Technologies, Hamburg, Germany, August 30-September 2, 1994, pp. 306-309. J. Van Baelen, C.L. Holloway, and S.B. Copeland.

We will first briefly describe the UHF Doppler/Interferometric Profiler developed at the National Center of Atmospheric Research (NCAR). Its principal characteristic is a simultaneous operation in both a 5 beam Doppler swinging mode and a multiple receiver interferometric mode. We will present in more details the interferometric technique used in both the vertical and the oblique beams, and we will discuss some advantages of the interferometric technique, especially regarding the temporal resolution of the wind field and the possible rejection of spurious echoes (such as birds and planes, but also ground and sea clutter), as well as some of its shortcomings.

Then we will compare wind profiles obtained with the conventional Doppler beam swinging technique and with the interferometric technique using identical data, and contrast these profiles with radio-sounding derived measurements (CLASS). We will show preliminary results which indicate that the multiple receiver interferometric technique compares favorably with the Doppler system, should provide optimal wind profiling capabilities.

Finally, we will investigate the ability of the Doppler/Interferometric Profiler to adequately estimate momentum fluxes, as well as virtual temperature profiles and sensible heat fluxes given that the system is also equipped to with a radio acoustic sounding system (RASS).

Characterization of Macrocellular PCS Propagation Channels in the 1850-1990 MHz Band, Proc. 3rd Internat. Conf. Universal Personal Commun., Sept. 27-Oct. 1, 1994, San Diego, CA. J.A. Wepman, J.R. Hoffman, and L.H. Loew.

Wideband propagation measurements for Personal Communications Services (PCS) were taken in the 1850-1990 MHz band in three different outdoor macrocellular (cell radii of 5 km) environments: flat rural, hilly rural, and urban high-rise. The data were analyzed to provide a description of the statistical behavior of the impulse responses in each cell. This analysis included RMS delay spread statistics, multipath power statistics, number of paths and path arrival time statistics, and effects of spatial diversity. The number of paths and path arrival time statistics provide particularly useful information in the design of tapped delay line models of the radio channel for PCS applications.

Radio Propagation into Buildings at 912, 1920, and 5990 MHz Using Microcells, Record of 3rd Internat. Conf. Universal Personal Commun., San Diego, CA, September 27 - October 1, 1994. S. Aguirre, L.H. Loew, and Y. Lo.

Continuous wave (CW) propagation experiments were conducted at 912, 1920, and 5990 MHz simultaneously using a narrowband system consisting of a fixed transmitter and a mobile receiver. The goal of the experiments was to quantify building penetration losses at various frequencies to determine the viability of indoor coverage using street microcells with base antenna heights below the roof level of nearby buildings. Statistical analysis included the computation of mean building penetration losses, standard deviations, cumulative probability distribution functions, and correlation coefficients.

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A Preliminary Look at Spectrum Requirements for the Fixed Services, An ITS Staff Study, May 1993. R.J. Matheson and F.K. Steele.

Polarized Transmission and Emission in the Middle Atmosphere (25-150 km) Near the Zeeman-Split Microwave O_2 Lines, National Radio Science Meeting, URSI/F3-8, Boulder, CO, January 1993, p. 154. H.J. Liebe, G.A. Hufford, and M.G. Cotton.

Millimeter-Wave Propagation in the Mesosphere, NTIA Report 89-249, September 1989, G.A. Hufford and H.J. Liebe.

Federal Standard 1045A Telecommuncations: HF Radio Automatic Link Establishment. National Communications System/Office of Technology and Standards, General Services Administration/ Office of Information Resources Management, October 18, 1993.

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ABBREVIATIONS

AAR	Association of American Railroads
ACATS	Advisory Committee on Advanced Television Systems
ACTS	Advanced Communications Technology Satellite
ADPCM	Adaptive Differential Pulse Code Modulation
ALE	Automatic Link Establishment
AMOS	Analysis of Microwave Operational Scenarios
ANSDIS	American National Standards for Information Systems
ANSI	American National Standards Institute
APCO	Association of Public Safety Communication Officials
ARNG	Army National Guard
ATCS	Advanced Train Control System
ASCII	American Standard Code for Information Exchange
ATM	Asynchronous Transfer Mode
BDPSK	Binary Differential Phase Shift Keying
BER	Bit Error Ratio
BFSK	Binary Frequency Shift Keying
BIB	Bureau for International Broadcasting
B-ISDN	Broadband Integrated Services Digital Network
BITB	Boulder Industry Testbed
BSS	Broadcast Satellite Service
CCIR	International Radio Consultative Committee
CCITT	International Telegraph and Telephone Consultative Committee
CD	Compact Disc
CDMA	Code Division Multiple Access
CELP	Code Excited Linear Prediction
CIR	Committed Information Rate Carrier-to-Interference Ratio
CISPR	International Radio Committee on Special Interference
COTS	Commercial Off-the-Shelf
CRADA	Cooperative Research and Development Agreement
CRC	Cyclic Redundancy Check
CRPL	Central Radio Propagation Laboratory
CRSMS	Compact Radio Spectrum Measurement System
CSPM	Communication System Performance Model
DAT	Digital Audio Tape
DBS	Direct Broadcast Service
DCS	Digital Cellular System
DDB	Doubly Dangerous Bridge (test)

DECT	Digital European Cordless Telephone (Standard)
DF	Direction Finding
DGPS	Differential Global Positioning System
DOC	Department of Commerce
DoD	Department of Defense
DOT	Department of Transportation
DQPSK	Differential Quadrature Phase Shift Keying
DS	Digital Signal
DSB	Double Sideband
DSP	Digital Signal Processing
EIA	Electronic Industries Association
EIRP	Effective Isotropic Radiated Power
EMC	Electromagnetic Compatibility
ESR	Errored Second Rate
FAA	Federal Aviation Administration
FAX	Facsimile
FCA	Frequency Control and Analysis
FCC	Federal Communications Commission
FCTDR	Frame-based Conformant Traffic Distortion Ratio
FEC	Forward Error Correction
FEMA	Federal Emergency Management Administration
FHSS	Frequency-hopped Spread Spectrum
FIPS	Federal Information Processing Standards
FLEWUG	Federal Law Enforcement Wireless Users Group
FM	Frequency Modulation
FPLMTS	Future Public Land Mobile Telecommunication System
FTP	File Transfer Protocol
FRA	Federal Railroad Administration
FSK	Frequency Shift Keying
FTSC	Federal Telecommunications Standards Committee
FTTA	Federal Technology Transfer Act (1986)
FY 94	Fiscal Year 1994: October 1, 1993 through September 30, 1994
GEMS	Ground Emitter Monitoring System
GEO	Geosynchronous Earth Orbit
GII	Global Information Infrastructure
GIS	Geographic Information Systems
GLONASS	Global Orbiting Navigation Satellite System
GOES	Geosynchronous Orbit Earth Satellite
GPS	Global Positioning System
GSM	Global System for Mobile (Communication)
HDTV	High Definition Television
HF	High Frequency (3-30 MHz)
HFIA	High Frequency Industry Association
HFSUM	HF Spectrum Utilization Mode
ICECAP	Ionospheric Communications Profile Analysis and Circuit Prediction Program

IEMCAP	Intrasystem Electromagnetic Compatibility Analysis Program
IFRB	International Frequency Registration Board
IHFSUM	Institute High Frequency Spectrum Use Model
INFOSEC	Information Systems Security
IONCAP	Ionospheric Communication Analysis and Prediction Program
IN	Intelligent Networks
I/Q	In-phase/Quadrature
IRAC	Interdepartmental Radio Advisory Committee
IRGF	International Reference Geomagnetic Field
ISDN	Integrated Services Digital Network
ISM	Industrial, Scientific, and Medical
ISO	International Organization for Standardization
ISTEA	Intermodal Surface Transportation Efficiency Act (1991)
ITF	Interoperability Test Facility
ITS	Institute for Telecommunication Sciences Intelligent Transportation System
ITSA	Institute for Telecommunication Sciences and Aeronomy
ITU	International Telecommunication Union
ITU-R	ITU Radiocommunication Sector
ITU-T	ITU Telecommunication Standardization Sector
IVHS	Intelligent Vehicle Highway System
JEM	Jammer Effectiveness Model
JSR	Jammer-to-Signal Ratio
JTC	Joint Technical Committee (on Wireless Access)
JTSSC	Joint Telecommunications Standards Steering Committee
LADGPS	Local Area Differential Global Positioning System
LAN	Local Area Network
LFMS	Low Frequency Measurement System
LMDS	Local Multipoint Distribution System
LMR	Land Mobile Radio
MAS	Millimeter-wave Atmospheric Sounder
MIRG	Mobile Impulse Response Generator
MMW	Millimeter Wave
MOSES	Microwave Operational Scenario Evaluation Software
MPM	Millimeter-wave Propagation Model
MSS	Mobile Satellite Services
NCAM	Network Connectivity Analysis Model
NCS	National Communications System
NII	National Information Infrastructure
NIST	National Institute of Standards and Technology
NOAA	National Oceanic and Atmospheric Administration
NS/EP	National Security and Emergency Preparedness

NSF	National Science Foundation
NSTAC	National Security Telecommunications Advisory Committee
NTIA	National Telecommunications and Information Administration
NTSC	National Television Standards Committee
OA	Office Automation
OFDM	Orthogonal Frequency Division Multiplexing
OSI	Open Systems Interconnection (model)
OSM	Office of Spectrum Management
OT	Office of Telecommunications
PACS	Personal Access Communication System
PC	Personal Computer
PCM	Pulse Code Modulation
PCS	Personal Communication Services
PEACESAT	Pan Pacific Education and Communications Eperiment by Satellite
PMO	Project Management Office Program Management Office
PN	Pseudonoise Pseudorandom Number
POC	Proof of Concept
PPS	Precise Positioning System
PSK	Phase Shift Keying
PSTN	Public Switched Telephone Network
QPSK	Quadrature Phase Shift Keying
RAC	Railway Association of Canada
RAIDER	Radio Analysis and Integrated Design Engineering Requirements
RBOC	Regional Bell Operating Company
RCAS	Reserve Component Automation System
REAMS	Radio Environment Automatic Measurement System
RF	Radio Frequency
RISC	Reduced Instruction Set Computer
RMS	Root Mean Square
ROSES	Radio Operational Scenario Evaluation Software
RSEC	Radar Spectrum Engineering Criterion
RSL	Received Signal Level
RSMS	Radio Spectrum Measurement System
RTE	Remote Terminal Emulation
SCPC	Single Channel per Carrier
SESR	Severely Errored Second Rate
SHARES	Shared HF Resources
SNR	Signal-to-Noise Ratio
SONET	Synchronous Optical Network
SPS	Standard Positioning System
SSB	Single Sideband
TDMA	Time Division Multiple Access
TIA	Telecommunications Industries Association
TIIAP	Telecommunications Information Infrastructure Assistance Program
USAR	United States Army Reserve

USDA	United States Department of Agriculture
WACS	Wireless Access Communication System
WAN	Wide Area Network
WAAS	Wide Area Augmentation System
WAPM	Wide Area Prediction Model
WARC	World Administrative Radio Conference
WLAN	Wireless Local Area Network
WPBX	Wireless Private Branch Exchange
ZPM	Zeeman-effect Propagation Model