Spectrum and Propagation Measurements

The radio spectrum is a natural resource that offers immense benefit to industry, private citizens, and government by supporting a wide range of radio and wireless applications for communications and sensing. Unlike many other natural resources, the spectrum is non-depleting so it can be used indefinitely. However, the rapidly increasing number of radio devices and active competition for improved access to the radio spectrum suggests that its effective use will require increasingly more complex knowledge of the existing signals environment, as well as understanding the technical and operational factors that can cause interference between systems that share the spectrum.

NTIA manages the Federal Government's use of the spectrum to ensure maximum benefit to all users while accommodating additional users and new services. Efficient and effective use of the spectrum is a key element in both the NTIA and the ITS missions.

The Spectrum and Propagation Measurements Division of ITS performs measurements of radio signals to support research and engineering enabling more efficient and effective use of the spectrum. Major tools in this work include the Radio Spectrum Measurement System (RSMS), a van full of very capable computer-controlled radio measurement devices, and the Table Mountain Field Site and Radio Quiet Zone.

The following areas of emphasis are indicative of the work done recently in this Division to support NTIA, industry, and other Federal agencies.

Areas of Emphasis

Radio Spectrum Measurement System (RSMS) Operations
The Institute uses the RSMS to perform measurements of emission characteristics of new or proposed systems, of spectrum occupancy to determine the level of crowding, of EMC characteristics, and to resolve interference problems. The project is funded by NTIA.

RSMS-4 Development
The Institute develops RSMS-4 measurement hardware and software capabilities to provide RSMS-4 systems with greatly improved measurement and digital signal processing modes. System software will provide very flexible control, remote monitoring, uniform data recording and storage, and powerful analysis and display routines. The project is funded by NTIA.

Table Mountain Research
The Institute uses the special facilities at an 1800-acre radio quiet zone to perform a wide range of critical spectrum measurements and research. This year such research has included DTV measurements, background noise research, and detailed radar measurements. The project is funded by NTIA.

Spectrum Efficiency Research
The Institute investigates ways that Federal agencies can make more efficient and effective use of the spectrum to accomplish their respective missions. Recently this work is evaluating the use of the 162-174 MHz band by Federal agencies in the Washington, DC area to assess the hypothetical merits of moving separate Federal mobile radio systems onto various types of common shared radio systems. This work is funded by NTIA.

Ultrawideband Regulatory Support
The Institute continues measurements to characterize ultrawideband (UWB) devices and interference to conventional radio systems. Current work includes measurements of devices that mix UWB techniques with frequency-hopping or other modes and technical consultation on proposed regulatory changes. The project is funded by NTIA.

Radio Spectrum Measurement System (RSMS) Operations

Outputs

- Measurements to determine emission characteristics of a maritime surface search navigation radar.
- Measurements to determine emission characteristics of pulsed frequency hopping signals used in advanced designs of an automotive collision avoidance radar.
- Measurements to verify bandwidth correction factor equations applied to various ultrawideband signals.
- Measurements to determine emission levels of broadband signals transmitted over power lines.

The Radio Spectrum Measurement System (RSMS) and its associated measurement operations are the result of an ongoing commitment of the National Telecommunications and Information Administration (NTIA) to accomplishing four critical spectrum management missions:

1. Measure the extent, patterns, and amounts of radio spectrum usage in the United States (through specialized measurements of individual bands and through broadband spectrum surveys).
2. Measure the radio emission characteristics of individual transmitters to ensure compliance with existing regulations. These transmitters include — but are not limited to — radars, communication links, and navigation transmitters.
3. Measure the electromagnetic compatibility (EMC) characteristics of Government and non-Government transmitters and receivers. These characteristics are used by NTIA's Office of Spectrum Management (OSM) to design band allocation specifications that maximize benefits and minimize future interference problems.
4. Resolve interference problems in cases where a Government radio system may be involved as a victim or interferer.

ITS's RSMS Operations Project is expected to respond to requests for evaluation of these issues through engineering, measurements, and analyses.

In October 2002, ITS used its state-of-the-art spectrum measurement capabilities to measure the spectrum emissions of a maritime surface search navigation radar at the Table Mountain Field Site and Radio Quiet Zone facility north of Boulder, CO. The measurements were performed for two reasons: (1) to determine the rate at which unwanted emission levels varied as a function of measurement bandwidth; and (2) to determine the amount of change that occurred in the shape of the radar spectrum when measurements were performed within the near field limit of the radar antenna. The results were used by NTIA/OSM, presented at the 2003 International Symposium on Advanced Radio Technologies (ISART), presented to the ITU-R Working Party 8B Radar Correspondence Group in London, UK, in June 2003, and will appear in an upcoming NTIA Report on measurement of radar emissions for compliance with the Radar Spectrum Engineering Criteria (RSEC).

In February 2003, NTIA personnel from ITS and OSM worked jointly with the Federal Communications Commission (FCC) and a private sector company to perform measurements on emissions from an advanced design of an automotive collision avoidance radar at the FCC lab at Columbia, MD. The measurements were performed to characterize the radar's spectrum emissions in radio bands that are used by some remote sensing satellites. Results were used by multiple Government agencies to determine the impact that such radar operations might have on some remote sensing satellite operations.

In May 2003, personnel from ITS performed measurements on simulated pulsed frequency hopping signals to further characterize emissions of advanced automotive collision avoidance radars. Results of these measurements were used by NTIA to develop certification measurement procedures to determine compliance with the FCC's emission limits.

Also in May 2003, ITS personnel conducted measurements on various ultrawideband (UWB) modulated signals to verify bandwidth correction factor

RSMS-4 performing measurements of broadband over power line in a residential neighborhood in September 2003 (photograph by B. Bedford).

equations that were the outcome of earlier modeling. The results of these measurements were used by OSM in response to the FCC's requested comments regarding a further notice of proposed rulemaking on UWB.

In June 2003, ITS personnel transported a portable radar spectrum measurement system to a facility in the United Kingdom for a comparative set of measurements on radar spectrum emissions. The measurements, performed near Portsmouth, were made side-by-side with a UK system that had been designed from concepts originated by ITS engineers. The comparative measurements were performed to determine whether two independently designed and constructed measurement systems would show the same spectrum result for the same radar. The results from the two systems (US and UK) were comparable and within the experimental error bounds of the systems.

Starting in August 2003 and continuing into FY 2004, ITS personnel performed measurements to determine the radio emission levels from broadband over power lines (BPL). This is a new technology that transforms power lines into network cables that can deliver broadband content over unshielded wires. Two field measurements, each lasting approximately 2 weeks, were conducted at different sites (see figure above). The data from these measurements will be used by NTIA in developing a response to a notice of proposed rulemaking issued by the FCC.

In September 2003, ITS personnel performed antenna pattern measurements on a National Weather Service (NWS) radar. The measurements were performed to assist the US Administration with a technical Contribution to ITU-R Working Party 8B, which deals with maritime mobile, aeronautical mobile, and radiodetermination services.

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RSMS-4 Development

Outputs

- Fully operational RSMS 4th generation measurement vehicle.
- Integrated measurement system — including new spectrum analyzers, digital oscilloscopes, vector signal analyzers, and signal detection devices.
- Functional data acquisition and system control software.

The 4th generation Radio Spectrum Measurement System (RSMS-4) consists of state-of-the-art tools (vehicle, software and hardware) necessary for making measurements to characterize spectrum occupancy, ensure equipment compliance, determine electromagnetic compatibility, and analyze interference problems. The development of RSMS-4 originated out of the recognized need to upgrade to the latest technology used in RSMS operations. RSMS operations, in turn, directly supports NTIA by providing critical measurement support for determining policies affecting both the public and private sectors.

The new RSMS 4th generation measurement vehicle (photograph by W.A. Kissick).

VEHICLE

A new measurement vehicle makes it possible to perform measurements efficiently and effectively. The vehicle enclosure has 60 dB effective shielding from all points, making this vehicle particularly suited for measurements in strong signal environments, as well as for noise measurements (where noise originating inside the vehicle could contaminate the measurements). Internet connections and routers are located throughout the enclosure, along with fiber optic control lines, multiple power outlets, and overhead cable racks. Three full-height instrument racks are available, with ample counter space, storage space, and head room. The racks can be moved forward for rear access, locked into place, or removed entirely.

The vehicle is powerful, easy-to-handle, and has sleeping space in the cab. A 20-kilowatt diesel generator provides for all electrical power demand, including full heating and air conditioning for extreme climates. Internet and shore power connections on the outside of the enclosure allow easy hook-up to local facilities. There are three 10-meter telescoping masts — two in the rear and one in the front. Extra brackets on the roof make it easy to mount antennas. All of this is accessible through a wide rear door and retractable staircase with handrails.

HARDWARE

Much new measurement equipment has been added, which provides substantial improvements to the already extensive inventory of measurement tools. The heart of the measurement system is four new spectrum analyzers that have excellent RF characteristics and powerful new digital signal processing capabilities. Two new vector signal analyzers (VSAs) allow 14-bit digitization in a 36-MHz IF bandwidth, backed up with an extensive software suite to perform complex signal analysis and demodulation. Two new, stand-alone, VXI-based channel analyzers allow surveying the radio environment, as well as digital acquisition when signals meet specified characteristics. They can also be used to trigger analysis by the VSAs. Also included are high speed digital signal processing chips that can be programmed for advanced detection criteria using open-architecture software.

Two new quad-input digital oscilloscopes with a front-end bandwidth of 500 MHz and maximum sampling rate of 8 GS/s have special smart-triggering capabilities and segmented memory. The latter allows efficient acquisition of pulsed signals with small duty cycles. Another new digital oscilloscope with a front-end bandwidth of 1 GHz and maximum sampling rate of 5 GS/s has specialized peak and sample detection capabilities, making it suitable for wide bandwidth acquisition and analysis — including pulsed signals. Finally, two new preselectors have been designed and tested and are currently under construction. They will filter and amplify, improving system sensitivity and allowing operation in large-signal environments.

SOFTWARE

The RSMS-4G software has an open-ended architecture that allows nearly unlimited expansion in many possible directions. Integral to this flexible architecture are instrument and measurement dynamic link libraries (DLLs). DLLs have been developed for several key pieces of measurement equipment (including spectrum analyzers, oscilloscopes, and preselectors). These DLLs contain command/query modules that interpret standardized commands common to the different equipment categories and a Virtual Front Panel that provides a user-friendly graphical interface for “manually” controlling the device via the computer. These DLLs, when completed, will provide a basis for rapid development of automated measurements with a wide range of instruments.

DLLs have also been developed for several different automated measurement procedures. These “measurement” DLLs also have a user-friendly graphical interface for setting up and monitoring the progress of a measurement. Common to all measurement DLLs is a carefully defined interface so that their use can be standardized. Three of these measurement routines were used extensively during the broadband over power line (BPL) measurements: a calibration procedure, a stepped frequency measurement, and an APD measurement.

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Table Mountain Research

Outputs

- Digital television field strength and video quality study.
- Radar emission spectrum measurements performed using new ITS-developed measurement system.
- Software for the simulation of non-Gaussian noise processes typically observed in urban and residential environments.
- Software to compute and plot the third- and fourth-order statistics of noise processes.

The Table Mountain Field Site and Radio Quiet Zone supports fundamental research into the nature, interaction, and evaluation of telecommunication devices, systems, and services. To achieve this goal, the Table Mountain Research Project actively solicits research proposals both from within ITS and from external organizations. This research serves to expand the knowledge base available to ITS, helps identify emerging technologies, and provides for the development of new measurement methods needed to study the characteristics of new devices and systems based on this technology. The results of the Table Mountain work are disseminated to the public via technical reports, journal articles, conference papers, web documents, and computer programs. Some highlights of the technical program in FY 2003 are presented below.

DTV Field Strength and Video Quality Study

In 2003, concerns that existing power limits placed on the broadcast industry might limit the availability of digital television (DTV) formed the basis for a DTV field strength and video quality study. In this study, a simulated home mounted on a flat bed trailer (see figures below) was used to compare the quality of a video signal received inside the structure at various locations around the area. The simulated home was used to eliminate the variability inherent in multiple structures, limiting the results to effects due to location and incident signal level. A DVD recording of the video signal was made with field strength levels included, and the results were summarized in an NTIA Technical Memorandum (see **Recent Publications** on next page).

Figure 1. Outside (top) and inside (bottom) of the ITS "Tool Shed Measurement System," used in the DTV field strength and video quality study (photographs by W.A. Kissick).

Characterization of Man-made Noise

Since the late 1960's, ITS has characterized man-made noise from measurement results. The first approach estimated amplitude statistics with hardware detectors, which were designed and built to measure average amplitude, root mean square amplitude, peak amplitude, and average logarithmic amplitude. Subsequent systems made use of an instrument to measure the complementary cumulative distribution or amplitude probability distribution (APD) with hardware circuitry. This instrument provided an estimate of first-order amplitude statistics that could be used to calculate amplitude statistics difficult to detect with hardware, such as the median amplitude. Today this instrument is routinely emulated in software using amplitude samples measured with a spectrum analyzer.

Unfortunately, for complete characterization, even the simplest Gaussian random process needs second-order statistics, e.g., those found in the auto-correlation function and corresponding power spectral density, in addition to the first order statistics of the APD. Man-made noise processes, often much more complex, need even higher-order statistics such as third- and fourth-order cumulants and corresponding poly-spectra. These higher-order statistics are based on complex noise voltage samples such as those obtained with a modern vector signal analyzer.

In FY 2003, the Table Mountain Research project completed several tasks to help engineers understand the importance of higher-order statistics in characterizing man-made noise. First, software was written to generate non-Gaussian noise processes previously observed in urban/residential environments. Next, software was written that calculated and plotted the third- and fourth-order statistics of these simulated random processes.

Currently there is much interest in evaluating methods to share the radio spectrum. Ultrawideband modulation and "junk bands" based on spectrum sharing etiquettes are but two examples. Since interference due to these methods is likely to be non-Gaussian, it is expected that knowledge of the higher-order statistics will be useful to both designers building demodulators and regulators writing emission specifications. In FY 2004, the Table Mountain Research project plans on measuring noise in existing junk bands to further the study of the importance of higher-order statistics.

Radar Emission Spectrum Measurements

Radar transmitters produce some of the highest effective radiated power levels in the entire radio spectrum. Therefore it is critical that radar emission spectra be accurately measured for conformance with emission masks such as the NTIA Radar Spectrum Engineering Criteria (RSEC). With that goal in mind, a program for the development of radar emission spectrum measurements has been established at the Table Mountain research facility. Although it is necessary to coordinate such temporary high-power measurements with other "quiet zone" users, this coordination is usually easily accomplished. Advanced measurement techniques (both hardware and software) are used to measure emissions from actual radar transmitters.

In FY 2003, an X-band maritime surface search navigation radar was brought to Table Mountain and a set of measurements were performed using the new ITS RSMS-4. Additional radars are expected to be brought there for measurement, and additional research into radar emission measurements will be performed in FY 2004.

Recent Publications

J. W. Allen and T. Mullen, "Digital television (DTV) field strength and video quality study," NTIA Technical Memorandum TM-03-405, Aug. 2003.

F. Sanders, "Dependence of radar emission spectra on measurement bandwidth and implications for compliance with emission mask criteria," in "Proceedings of the International Symposium on Advanced Radio Technologies," J. W. Allen and T. X Brown, Eds., NTIA Special Publication SP-03-401, Mar. 2003.

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Spectrum Efficiency Research

Outputs

- Development of signal capacity model.
- Signal capacity results for Washington, DC area.

NTIA is the Executive Branch agency responsible for spectrum management of Federal users. As demand for spectrum has increased, NTIA and the Federal Communications Commission (FCC) have continued to examine ways to improve the efficient use of the spectrum. For example, in June 2003, President Bush released a new initiative that directs the development of a radio spectrum policy for the 21st century to better manage the Nation's airwaves, enhance homeland security and economic security, increase benefits to consumers, and ensure U.S. leadership in high-tech innovations.

A major use of Federal spectrum is to support communications with agents from many different agencies. Typically, each separate Federal agency builds a mobile radio system, which it uses to talk with its own agents. Because there are so many of these independent radio systems, NTIA has worked hard to make these systems work more efficiently, studying and promoting isolated individual technical efficiency factors,[1] with arguably only moderate success. ITS and NTIA's Office of Spectrum Management (OSM) determined that greater improvements in Federal spectrum efficiency might be obtained by studying broader aspects of how agencies provide services to their mobile users. Specifically, we decided to compare the relative effectiveness of the many single-agency mobile radio systems now used to a possible future radio system shared between multiple agencies.

Since the 162-174 MHz band near Washington, DC is the most intensely used Federal mobile radio band, we decided to study it first. The first phase of the study (described in these pages) analyzes current Federal use of the radio spectrum by developing a quantitative model of the "signal capacity" (SC) of agency use. The second phase — planned for completion next year — will use these quantitative results to develop modern alternatives to the current individual agency systems. Depending on the apparent overall benefits predicted, one or more concepts could be selected for further development.

[1]R.J. Matheson, "A survey of relative spectrum efficiency of mobile voice communications systems," NTIA Report 94-311, Jul. 1994.

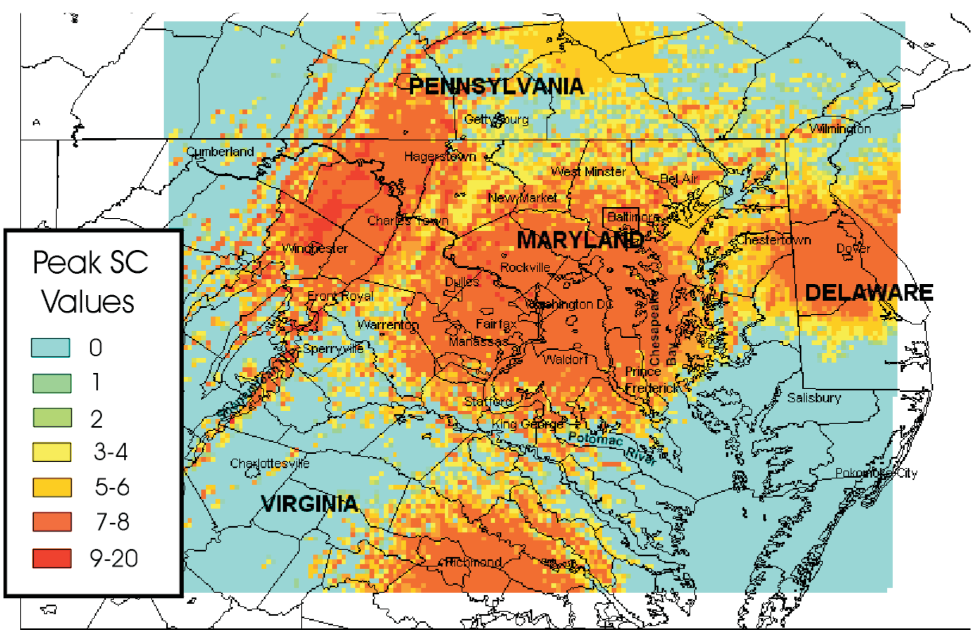

Figure 1. Example of peak signal capacity map for a few selected Federal agencies.

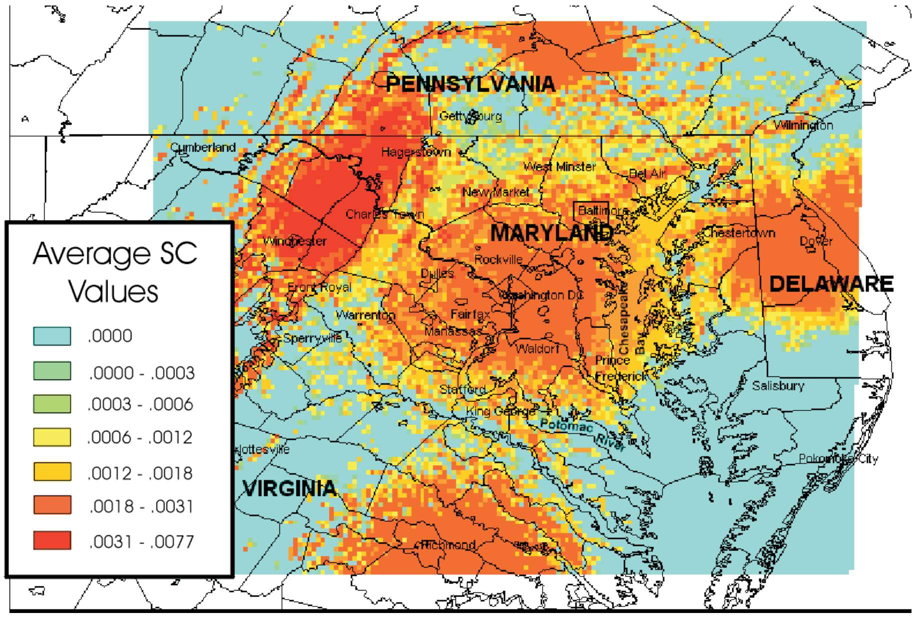

Figure 2. Example of average signal capacity map for a few selected Federal agencies.

The signal capacity model counts the number of independent radio channels that can be received by a mobile user at every location near Washington, D.C. Maps of signal capacity values for all Federal agencies were assembled, and examples are shown in Figures 1 and 2. Although the signal capacity data could have been derived in several ways (e.g., RSMS channel occupancy measurements at multiple sites), we decided to use the Government Master File (GMF) of all federal radio licenses with propagation coverage prediction programs to obtain the needed data. The GMF contains reasonably complete data on all Federal transmitters, and a terrain-based Longley-Rice model was used to calculate signals from each transmitter at 1-mile increments over an area 200 miles on a side.

Different signal capacity algorithms were developed for various mobile radio architectures, dependent on how the SC values added if adjacent sites in a network both provided coverage to a single location. In simulcast systems and some repeater systems, the coverage from adjacent sites provides the same signal content, so coverage from adjacent sites does not increase SC values. However, other architectures (e.g., trunked radio systems) provide independent signals from adjacent sites, so SC values increase according to coverage from multiple sites. Following much coordination with agency representatives, NTIA personnel assigned specific “function codes” to each GMF entry, which told the SC computer program how data from each assignment was to be analyzed. Once the SC values are calculated for a network of assignments, maps from individual networks can be added together on a point-by-point basis to get SC maps for much large collections of users.

Figure 1 (on the previous page) shows an example of a Peak SC map for a few selected Federal agencies in the Washington area. Note that a Federal user in downtown Washington or at outlying Federal installations could receive as many as 20 independent signals. Many rural areas have much smaller SC values; in fact, there are many areas that could not receive any signals at all from the selected group of agencies.

Figure 2 (above) shows a similar map of Average SC values, produced from Average SC network maps of the same selected agencies. Average SC maps contain values showing the average number of independent users per square mile that could be supported by the analyzed radio networks. The average SC maps will allow site capacity to be scaled according to the coverage area of that site in follow-on system design work based on these maps. The ratio of peak SC to average SC values gives an approximate measure of the coverage area of typical sites. In this case, for example, the maximum graphed values are peak = 20, average = .0077. The ratio between these values shows a typical site coverage area of 2900 square miles, corresponding to a circle with a radius of 29 miles.

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Ultrawideband Regulatory Support

Outputs

- Comments to NTIA on many proposed changes in UWB regulations.
- Monitoring ITU-R activities in UWB Task Group 1/8.
- Measurements to better understand new mixed-mode UWB devices.

In May 2000, the Federal Communications Commission (FCC) released a Notice of Proposed Rule Making on ultrawideband (UWB) systems, asking for a wide range of information on these systems, interference from these systems, and proposals for how to regulate them. At that time, technical opinion differed widely on how UWB systems interact with traditional radio systems, and how they should be regulated. In FY 2000 and 2001, ITS staff made extensive measurements to characterize UWB device emissions. ITS staff also made extensive measurements on UWB interference to various types of GPS receivers. This work was summarized in NTIA Reports 01-383, 01-384, and 01-389.[1] Closely following this work, engineers at NTIA's Office of Spectrum Management (OSM) used ITS measurements to predict how UWB devices would interfere with Federal systems and GPS. These predictions were summarized in NTIA Special Publications 01-43, 01-45, and 01-47.[2]

[1]W.A. Kissick, Ed., "The temporal and spectral characteristics of ultrawideband signals," NTIA Report 01-383, Jan. 2001.

J. R. Hoffman, M.G. Cotton, R.J. Achatz, R.N. Statz, and R.A. Dalke, "Measurements to determine potential interference to GPS receivers from ultrawideband transmission systems," NTIA Report 01-384, Feb. 2001.

J.R. Hoffman, M.G. Cotton, R.J. Achatz, and R.N. Statz, "Addendum to NTIA Report 01-384: Measurements to determine potential interference to GPS receivers from ultrawideband transmission systems," NTIA Report 01-389, Sep. 2001.

[2]P.C. Roosa, Jr. , et al., "Assessment of compatibility between ultrawideband devices and selected Federal systems," NTIA Special Publication 01-43, Jan. 2001.

D.S. Anderson, E.F. Drocella, S.K. Jones, and M.A. Settle, "Assessment of compatibility between ultrawideband (UWB) systems and Global Positioning System (GPS) receivers," NTIA Special Publication 01-45, Feb. 2001.

D.S. Anderson, E.F. Drocella, S.K. Jones, and M.A. Settle, "Assessment of compatibility between ultrawideband (UWB) systems and Global Positioning System (GPS) receivers (Report Addendum)," NTIA Special Publication 01-47, Nov. 2001.

The technical and commercial communities continue with many activities needed to more exactly (and often more broadly) define the operational parameters for UWB devices. Although few actual commercial UWB devices have been sold to the public yet, many devices have been under intensive technical review. These include proposed 802.11 devices operating near the 5-GHz band and short-range automotive radars operating near 24 GHz. Since many of the proposed UWB devices will use UWB modulation mixed with frequency hopping (FH) or other modulations, there has been much activity in clarifying how these "mixed modes" should be characterized and regulated. The FCC released a Memorandum Opinion and Order and a Further Notice of Proposed Rule Making on March 12, 2003. This document proposed many significant changes in the details of how various mixed-mode devices should be categorized and measured. ITS has continued monitoring these proposed changes for technical implications and providing comments to NTIA for possible policy changes.

ITS also participated in the activities of ITU-R Task Group 1/8, dealing with issues of defining and regulating UWB devices on an international basis. Although UWB devices are typically very short range and would not normally require international regulation, such devices are also very transportable and devices manufactured for use in one country could easily find their way into many other countries. Therefore, TG 1/8 is studying UWB devices to understand their operation and to discuss ways to develop compatible standards for such devices.

ITS has also made additional measurements on several types of UWB devices in FY 2003 to help clarify NTIA's understanding of UWB devices. One series of measurements provided information on how measurement readings change when the pulse repetition frequency (PRF) of a UWB device approaches the bandwidth of the measurement system. This information was needed to more precisely analyze possible UWB interference.

A series of measurements were also made by ITS on a short-range 24-GHz automotive radar that incorporated short pulses and frequency hopping. The measurement test set-up is shown in Figure 1. Although the tested device included many possible operational modes, a typical pulse lasted 0.3 microseconds and had a bandwidth of about 4 MHz. The remainder of the 500-MHz minimum bandwidth needed to allow the device to be included under the UWB rules was obtained by frequency-hopping the pulse over a 500-MHz range. This UWB device is an example of several new devices that meet some UWB characteristics, but operate somewhat differently from a pure UWB device. The need to make correct decisions about how such devices should be measured, and what limits should be applied to them, furnishes the motivation to undertake these measurements of various prototype devices.

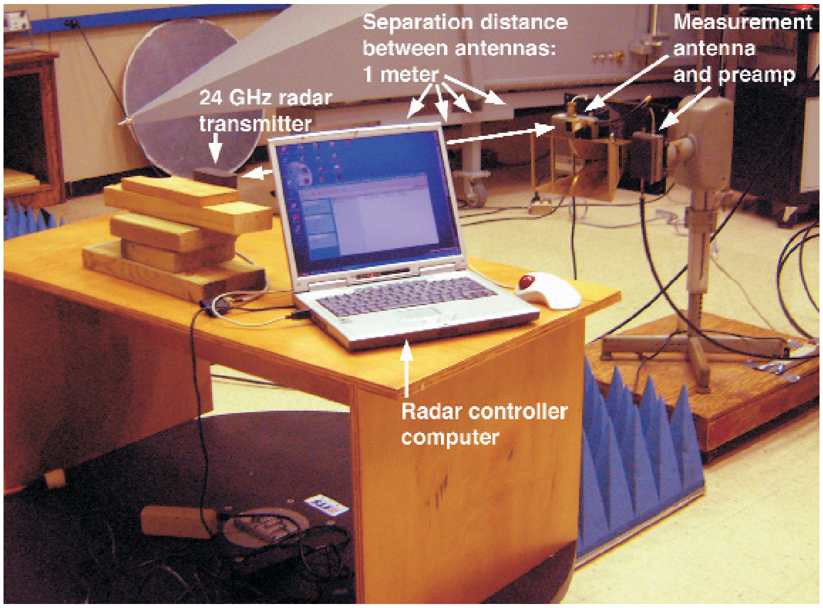

Figure 1. 24-GHz radar setup (photograph by F.H. Sanders).

Figure 2 shows an emission spectrum of the automotive radar when measured with an RMS detector having various integration times. It is typical of such measurements that "arcane details" like measurement integration time can significantly affect the numeric readings of procedures intended to set limits on the level of signals produced by these devices. Therefore, it is necessary to carefully note proposed regulatory changes in measurement details along with the specification of numerical limits on device emissions.

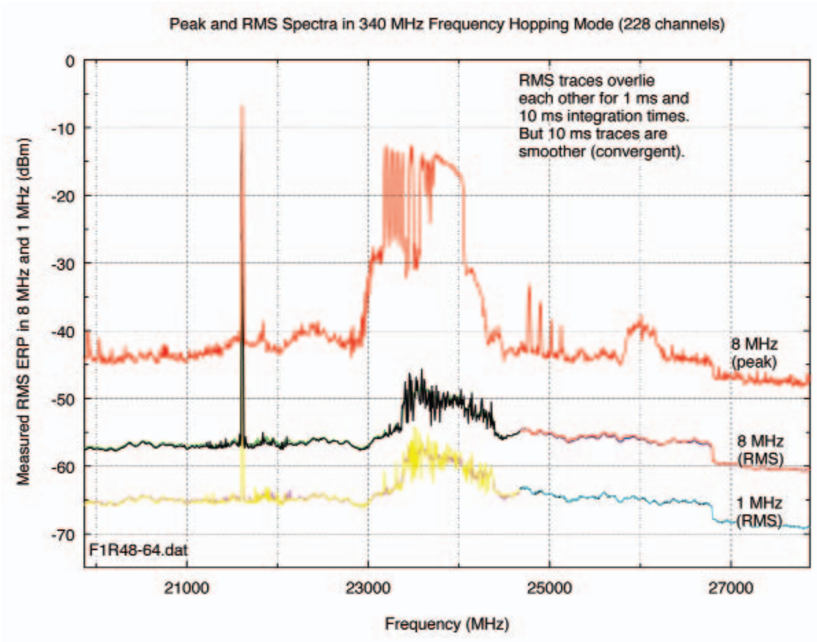

Figure 2. Emission spectrum of 24-GHz radar.

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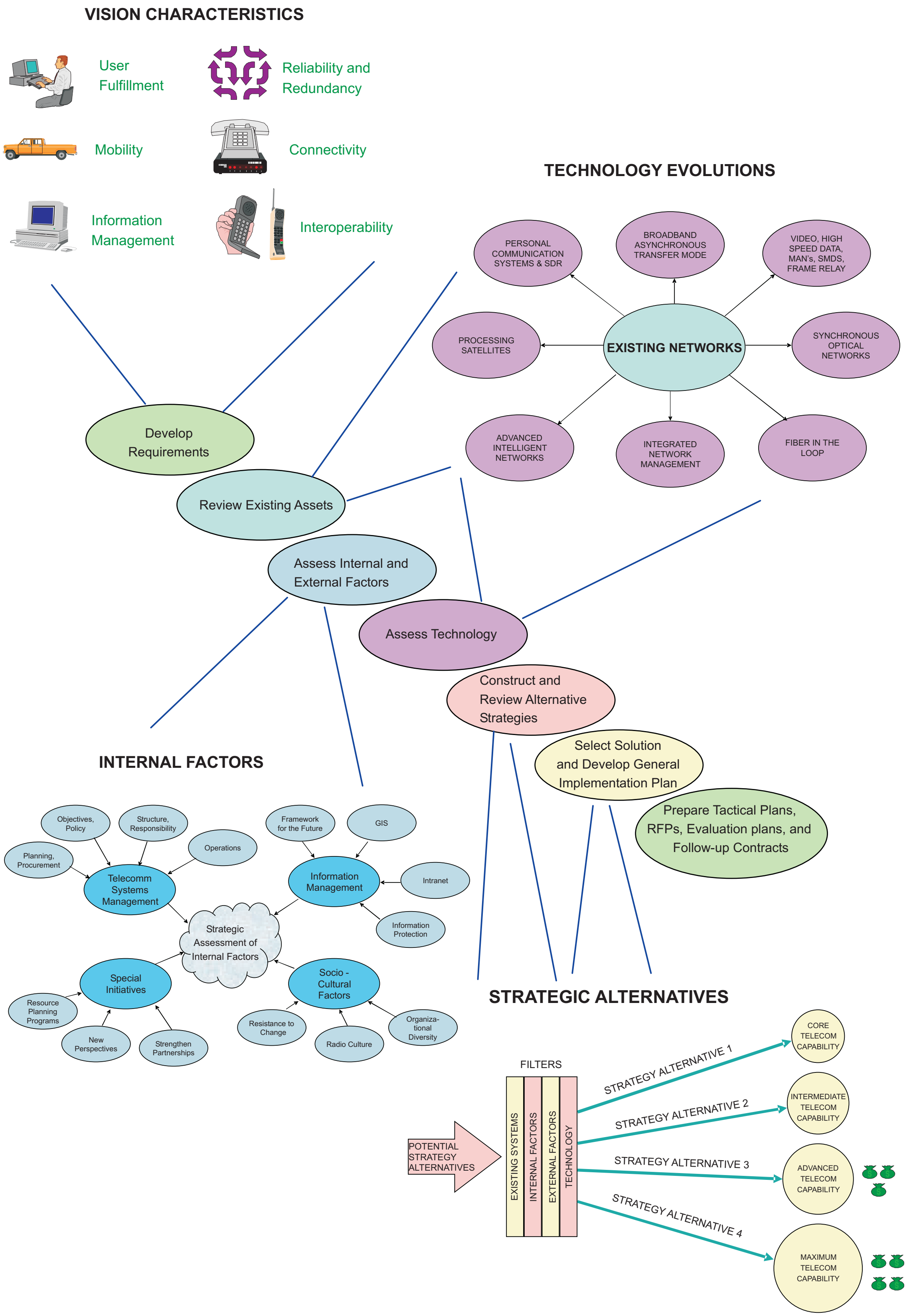

Overview of the telecommunications and information technology planning process.