Spectrum and Propagation Measurements

The radio spectrum is a natural resource that offers benefit to all of humanity by supporting all radio and wireless applications for communications and sensing. Unlike many other natural resources, the spectrum is non-depleting so it can be used indefinitely; but its shared use requires planning and coordination to ensure its effectiveness and to avoid interference. Efficient and effective use of the spectrum is a key element in both the NTIA and the ITS mission. NTIA manages the Federal Government's use of the spectrum to ensure maximum benefit to all users while accommodating additional users and new services.

The Spectrum and Propagation Measurements Division performs measurements of radio signals to support research and engineering promoting more efficient and effective use of the spectrum, and opening up more spectrum at ever-higher frequencies. 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

Spectrum Compatibility Measurements

The Institute participates in measurements of the emission characteristics of new or proposed systems to help determine their compatibility with each other and with existing systems. The project is funded by NTIA.

Spectral Assessment of Government Systems

The Institute performs measurements on new and established Federal systems to determine their emissions characteristics, to confirm proper operation, or to identify and mitigate interference or other incompatibilities. Projects are funded by NTIA.

Radio Spectrum Measurement System Upgrades

The Institute uses its Radio Spectrum Measurement System (RSMS) to make spectrum occupancy measurements, and to help assess interference and compatibility issues. To keep pace with technological changes in radio systems, the RSMS is being upgraded with hardware and better signal processing to support faster measurements, higher frequencies, and new modulation methods. The project is funded by NTIA.

Ultrawideband Signal Characterization

The Institute performs measurements of both the temporal and spectral characteristics of the time-domain-modulated radio technology called ultrawideband (UWB). Measurement methods are developed to identify the technical characteristics of UWB signals when received (observed) in various bandwidths. The project is funded by NTIA.

Effects of Ultrawideband Signals on GPS Receivers

The Institute identifies and analyzes the effects that a variety of UWB signals may have on various critical receiver systems used with the Global Positioning System (GPS). The resulting information is used to develop frequency management criteria (e.g. coordination distance) or new rules and regulations. The project is funded by NTIA, the U.S. Air Force, and the Federal Aviation Administration.

Spectrum Compatibility Measurements

Outputs

- Measurements on maritime mobile radio compatibility with the automatic identification systems (AIS) used by marine traffic at New Orleans.
- Measurements of ultrawideband (UWB) transmitter emissions as a function of measurement bandwidth at Columbia, MD.
- Measurements of EMC between a UWB transmitter and a variety of air traffic control radionavigation systems at Oklahoma City, OK.

The introduction of new-technology systems can cause electromagnetic compatibility (EMC) problems when such systems are deployed in proximity to existing ones. NTIA proactively tracks the development of such new technologies and routinely performs EMC analyses and measurements to minimize the extent of such problems involving Government systems.

In FY 2000, ITS used suitcase measurement systems in New Orleans to determine EMC parameters between marine mobile radiotelephones and automatic identification systems (AIS) used by marine traffic. Interference-to-noise (I/N) protection ratios were measured, and the results were forwarded to the NTIA Office of Spectrum Management (OSM) for use in a report that is currently in a draft form.

Ultrawideband (UWB) transmitter emissions were measured at the Federal Communications Commission (FCC) laboratory in Columbia, MD. These initial measurements were performed to determine how UWB signals coupled into traditional radio receivers would change as a function of receiver bandwidth. New measurement techniques were developed for this task, utilizing a newly available wideband intermediate frequency (IF) section for a spectrum analyzer. Data results from the measurements were forwarded to OSM and to other ITS personnel for use in the development of theoretical models for coupling between UWB transmitters and non-UWB radio receivers.

Figure 1. An ultrawideband (UWB) transmitter antenna mounted on top of a mast on the Radio Spectrum Measurement System (RSMS) van with an ARSR-4 radar tower in the background. The UWB transmitter emission effects were monitored at the ARSR-4 receiver (photograph by F.H. Sanders).

Figure 2. The ARSR-4 radar antenna feed, which received the UWB emissions transmitted from the RSMS system shown in Figure 1 (photograph by F.H. Sanders).

UWB emissions are also a concern to Government spectrum managers, due to the possibility that such systems might have the potential to cause interference to air traffic control systems such as radars and air traffic control beacon interrogators (ATCBI). To quantify the maximum UWB emission levels that might be allowed in the vicinity of such receivers without causing interference effects, ITS used the Radio Spectrum Measurement System (RSMS) at the Federal Aviation Administration (FAA) center at Oklahoma City, OK. The RSMS performed quantitative tests and measurements on several FAA receivers at that location. The receivers were the ASR-8, ASR-9, and ARSR-4 air traffic control radars, and the ATCBI-5 beacon system. A programmable UWB test transmitter with a custom-controllable output was used to couple signals into these receivers, both via cables and via radiation from various distances outdoors.

For these measurements, techniques were developed to monitor the levels at which UWB signals were occurring within the receivers. A technique was also developed to measure the coupling factors between the radar and beacon receivers and the UWB transmitter as a function of distance between the transmitter and receivers. It was determined that the coupling factors did not increase without limit as the distances between the transmitter and the receivers were reduced. Rather, a maximum coupling level was achieved within a non-zero distance from all of the receivers, and this level decreased as the UWB transmitter moved in closer (and into the "dead spot" underneath the receiver antenna pattern).

Measurements on receiver performance were performed with the UWB transmitter located within the maximum coupling zone for each receiver. The UWB emission levels were varied to determine the levels at which degradation to receiver performance was minimized. The results were summarized and forwarded to OSM for incorporation into NTIA Reports on this and other UWB compatibility studies by NTIA.

Recent Publication

W. Kissick, Ed., "The temporal and spectral characteristics of ultrawideband signals," NTIA Report 01-383, Jan. 2001.
http://www.its.bldrdoc.gov/pub/ntia-rpt/01-383

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Spectral Assessment of Government Systems

Outputs

- Spectrum emission measurements on tactical and anti-tactical ballistic missile (ATBM) military radars.
- Draft New Proposed Recommendation on radar emission spectrum measurement techniques to the ITU-R, in support of the U.S. Administration.

Increasing demands are being placed upon radio spectrum worldwide to accommodate new-technology systems such as International Mobile Telecommunications 2000 (IMT-2000). Such spectrum demands can result in electromagnetic compatibility (EMC) problems that threaten Government radio operations. Further, in the event that new or existing Government systems do create or experience EMC problems, it is necessary to resolve these problems promptly and efficiently. ITS provides extensive EMC measurement and analysis capabilities for preventing potential EMC problems and solving existing ones.

A number of Administrations in the International Telecommunication Union (ITU) have recently proposed that spectrum bands used by various U.S. radars and radionavigation systems may be shared with the new communications technologies. In support of the U.S. Administration, ITS has undertaken a technical effort to determine the nature of and the extent to which EMC problems may occur when bands are shared between radars and other services. Further, to ensure that radars continue to be provided with a sufficient amount of spectrum, ITS has undertaken a significant effort to ensure that foreign Administrations accurately and adequately measure the spectrum emissions from their own existing radar systems.

Figure 1. ITS measurements in progress on maritime surface-search and navigation radars at a Ministry of Defense facility at Funtington, UK. A suitcase version of the Radio Spectrum Measurement System (RSMS) was used inside the loaned van. The collapsible parabolic antenna is trained on radars, located about 1/8 mile away (photograph by F.H. Sanders).

Figure 2. Detail of the Figure 1 measurement system, showing the measurement system as configured within the van (photograph by F.H. Sanders).

In FY 2000 ITS performed emission measurements on Department of Defense (DoD) radar transmitters at Syracuse, NY. These measurements were intended to show both the extensive nature of the emissions from these radars, and also the desirability of performing the measurements in accordance with techniques previously developed by ITS. These data were used to support the U.S. Administration position at the ITU.

The measured DoD transmitters included radars designated AN/FPS-117 and AN/TPS-59. The radars are used for long-range air surveillance, and one (the TPS-59) incorporates anti-tactical ballistic missile (ATBM) capabilities. The measurements were performed with the NTIA/ITS Radio Spectrum Measurement System (RSMS). The radar was allowed to radiate and scan the sky in normal operational modes while the RSMS received its signals at a distance. A variety of measurement parameters were used to demonstrate the effect on measurement results. In addition, measurements of pulse shapes were performed in different bandwidths to demonstrate the time waveforms to which receivers near such radars will be subjected at selected frequencies, including GPS bands.

In June 2000, a suitcase radar measurement system was transported to Funtington, UK, to demonstrate those measurement techniques to selected ITU members (France, Japan, Germany, and the UK), as shown in Figures 1 and 2. The suitcase system was used to perform measurements on maritime navigation radars with the delegates in attendance. A seminar on ITS radar measurement and calibration techniques was provided by NTIA Office of Spectrum Management (OSM) personnel at Southampton, UK, in connection with this effort.

In October, ITS personnel traveled to the ITU-R Working Party 8B meeting in Geneva, Switzerland to support a Draft New Proposed Recommendation for the measurement of radar emission spectra. Its final approval as an ITU Recommendation is pending, subject to additional efforts by the French and other Administrations to develop the measurement techniques demonstrated at Funtington, UK, and used earlier at Syracuse, NY.

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Radio Spectrum Measurement System Upgrades

Outputs

- Determination of wideband configuration and digitizer requirements.
- Design of preselector and RF control unit.
- Preliminary revision of RSMS software.

For over 25 years, the U.S. Department of Commerce Radio Spectrum Measurement System (RSMS) program has kept track of radio spectrum usage and resolved interference problems involving Government radio systems in the United States. Since 1973, this mobile Government facility (and sometimes its suitcase-transportable variants) has performed its mission at dozens of locations across the lower forty-eight states, as well as at Anchorage, AK; Adak, AK; Guam; Diego Garcia (BIOT); and Scotland (UK).

The RSMS program is a result of the ongoing commitment of NTIA's Office of Spectrum Management (OSM) to accomplishing three critical spectrum management missions: (1) Determine the extent, patterns, and amounts of usage of U.S. radio spectrum (particularly through broadband spectrum surveys between 30 MHz to 20 GHz); (2) Analyze emissions from Government and non-Government transmitters to prevent electromagnetic compatibility problems (interference) from occurring; and (3) Resolve radio interference problems if they involve one or more Government systems.

The RSMS is a state-of-the-art spectrum measurement and analysis capability that incorporates automated, semi-automated, and manual techniques for the measurement and analysis of radio emissions from the following types of transmitters: high-power radars; mobile radios and associated base stations; navigation beacons and transponders; point-to-point microwave links; earth station transmitters; and low power device emissions, such as those generated by FCC Part 15 (low power) and FCC Part 18 (Industrial, Scientific, and Medical (ISM)) units.

The RSMS is now in its third generation of design and operation by ITS. Although RSMS III is a powerful measurement tool, its effectiveness as a state-of-the-art spectrum measurement system is being eroded by rapid advances in radio technology. Therefore, a fourth-generation upgrade has been proposed: RSMS IV. This upgrade is intended to provide flexibility for different system configurations as well as for future expanded capabilities. It will provide a soft transition between the current and future systems, adding to the present capabilities rather than creating an entirely new system. The goals of

Radio Spectrum Measurement System (RSMS) III, parked outside Wing 4 of the Department of Commerce Boulder Laboratories (photograph by F.H. Sanders).

the upgrade and progress made in FY 2000 are described below.

Expansion of measurement system bandwidth.

The RSMS has a bandwidth of 3 MHz, wide enough for most applications. However, there is a need to expand to wider bandwidths to measure some of the newer spread spectrum systems and proposed ultrawideband (UWB) systems. To meet this goal requires expanding the bandwidth of the measurement spectrum analyzer to 100 MHz, redesigning the front end preselector module, and modifying the acquisition software. The spectrum analyzer upgrade is to be accomplished in two steps. The first step is the replacement of the spectrum analyzer IF section with an IF section capable of 100-MHz bandwidth (accomplished in FY 2000). The second step (planned for FY 2001) will complete the expansion through the purchase of an RF unit capable of 100-MHz bandwidth. An internal spectrum analyzer tracking filter in the RF unit can be used for bandwidths up to 35 MHz. For bandwidths greater than 35 MHz, external broadband YIG tracking filters are required which have been designed into the next generation front-end preselector module. RF coverage for the spectrum analyzer is 100 Hz to 26.6 GHz. Software modifications are further required to incorporate the capabilities of the wide bandwidth spectrum analyzer into the current and future proposed acquisition software.

Digital signal processing (DSP) capabilities.

Real-time DSP capabilities will be incorporated into RSMS IV to allow signal processing in ways not possible through traditional analog means (e.g. sharp filtering with flat group delays). The first step was the purchase of a vector signal analyzer (VSA), a high speed, wide dynamic range digitizer which interfaces through the spectrum analyzer. The VSA is VXI based, has a 40-MHz baseband bandwidth, a 100-MHz sample rate, with a 15 equivalent bit digitizer. To achieve the full 80-MHz equivalent RF bandwidth, as well as obtain phase and time domain information, both the co-phase and quadrature-phase channels are required. This year, only a single channel was purchased, but the second baseband channel is slated for a future acquisition. To complete the system requirement for digital signal processing, both hardware and software changes are required. For phase and time domain information it has been necessary to design the hardware with minimal phase distortion and to utilize special calibration techniques to deconvolve the system effects. Modifications to the current acquisition software will also be required to incorporate the VSA.

Front-end hardware upgrade.

Upgrade of the RSMS has required additional hardware upgrades, including new preselector and RF controller modules. The preselector module has been designed with particular attention given to versatility for inclusion into suitcase applications. In addition, a wideband YIG tracking filter has been added, along with provisions for 18-26 GHz and 26-40 GHz block down-converters, and direction finding (DF) capabilities. The RF controller design has been modified for versatility, so it can be used in a suitcase application.

Software upgrade.

Objectives of the software upgrade project include transitioning to Windows® based software, expanding measurement capabilities, revising the file output format, allowing for growth and multiple programmer input, and providing a soft transition for processing software. To transition to Windows® the choices were: (1) rewrite the current software, (2) modify software developed for the Radio Frequency Interference Monitoring System (RFIMS), or (3) start from scratch. The decision was made to modify both the current acquisition software (better suited for suitcase applications and flexibility) and the RFIMS software (which has expanded capabilities and enhanced record keeping of calibrations and equipment states). Several tasks were identified for modification of the RFIMS software, including (1) incorporating hardware changes, (2) increasing flexibility, (3) adding key procedures to the scheduler, (4) incorporating a modulation domain analyzer, (5) changing the file structure, (6) adding multiple antenna port selection, (7) adding a file translation program for analysis tools, and (8) upgrading analysis tools for the new file structure. In FY 2000 the following tasks were completed: Global changes were made to the current RFIMS software to transform it into RSMS software. The recommended file structure was determined. Development of the modulation domain analyzer software was begun. The scheduler and the swept / m3 were added.

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Ultrawideband Signal Characterization

Outputs

- A description of time and spectral characteristics of UWB signals based on analysis, simulation, and measurements.
- Development of UWB measurement and modeling techniques
- Measurements of UWB interference to three Federal systems.

Because the radio spectrum is a limited resource, a wide variety of creative approaches have been proposed for increasing the number of users that can occupy it. Recently, an approach called ultrawideband (UWB) technology has been developed, which employs very-short-duration electrical impulses to provide sensing and communications functions. Although the UWB pulses contain energy that spreads across wide stretches of spectrum already containing many licensed radio systems, UWB proponents claim minimal interference to existing users, due to the very low spectral power density of UWB signals. However, many users of traditional radio systems fear that UWB signals may cause massive interference.

ITS performed a major study to assist with assessing these claims. The results of this study provide critically needed data and modeling tools for decision-making regarding the deployment and potential ubiquitous use of UWB transmitters. A theoretical analysis of UWB signals was performed to provide insights into how UWB signals affect various types of RF systems. The analytical results are also useful for the validation and interpretation of measurements. An analysis of proposed UWB pulse position modulation schemes yielded the power spectrum and some band-limited signal statistics. From the signal statistics, a method was developed for predicting when a UWB signal is approximately Gaussian.

UWB signals were measured as full-bandwidth pulse shapes, showing temporal characteristics such as the peak voltage and pulse widths (Figure 1). Since these pulses contained sub-nanosecond features, these measurements were technically challenging and required specialized expertise and facilities. Fast Fourier Transforms (FFTs) were performed on the pulse shapes to yield power spectra and field strength graphs (Figure 2). These graphs provided a reference set for comparison of spectrum measurements made with bandwidth-limited equipment.

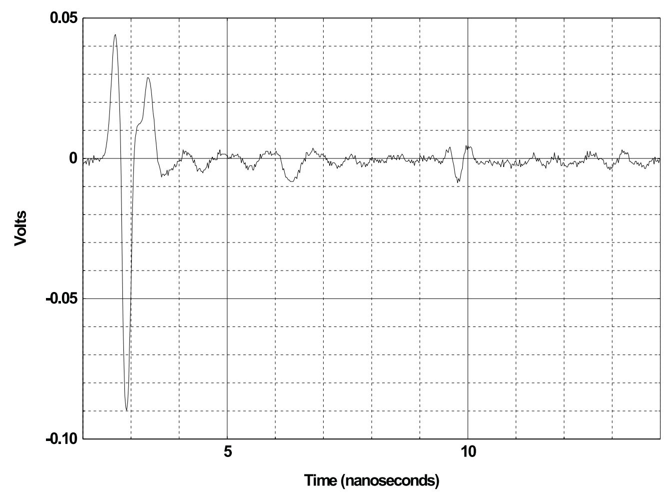

Figure 1. Full bandwidth pulse shape.

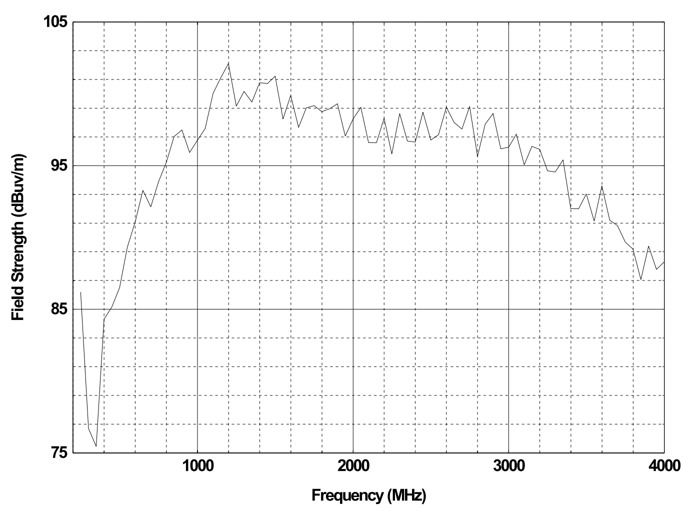

Figure 2. FFT spectrum from full bandwidth pulse shape.

Measurements were also performed using commercial-off-the-shelf (COTS) bandwidth-limited equipment like spectrum analyzers. These bandwidth-limited COTS measurements are important for several reasons: They provide a more realistic measurement approach for many commercial test laboratories; they give a more realistic indication of how UWB signals interact with traditional narrowband radio systems; and they permit a realistic study of the effects of various UWB modulation techniques such as dithering and gating. A major aspect of UWB signal characterization is that UWB signal amplitude and characteristics are highly dependent on measurement conditions, especially receiver bandwidth. Measurement techniques were developed for determining UWB signal characteristics as a function of the measurement bandwidth, the pulse repetition frequency, pulse modulation, gating, etc. One important conclusion was that the COTS measurements gave emission spectrum results very similar to the full-bandwidth FFT results.

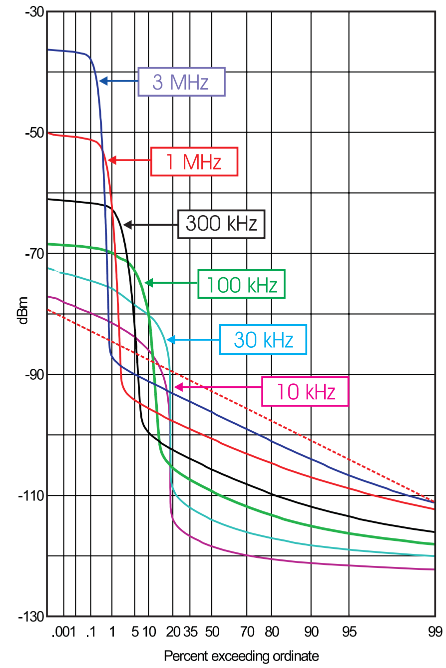

Figure 3. APDs measured in various bandwidths.

Amplitude probability distributions (APD) were developed as a useful way to describe UWB signals as a function of measurement bandwidth (Figure 3). APDs also were used to compute the values equivalent to several detector functions commonly found in measurement equipment (e.g., peak, RMS, average voltage, average log). The wide range of values for computed detector results (Figure 4) clearly show the importance of tightly specifying the correct measurement procedures for compliance with future UWB regulations. They also suggest that modifications to the proposed FCC Part 15 measurement procedures would provide more useful answers for UWB devices.

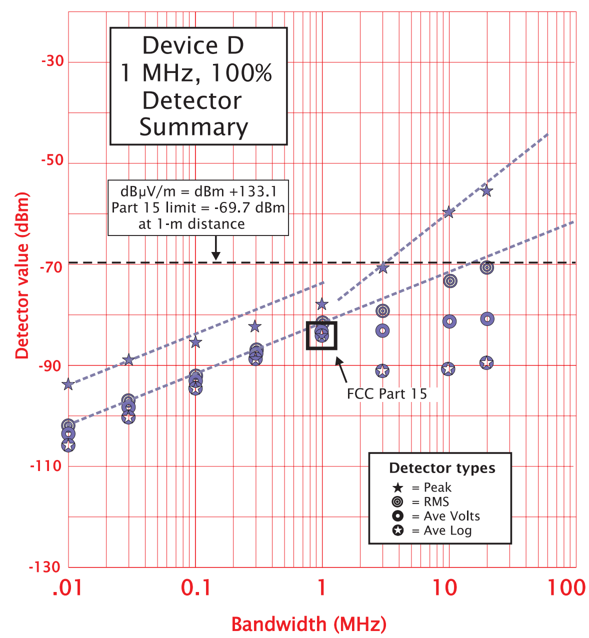

Figure 4. Detector summary, UWB device with 1-MHz average PRR.

Due to a potentially large proliferation of UWB devices, it is important to understand the effects of an aggregation of such devices. A statistical model was developed that can be used to calculate the power received from UWB devices randomly distributed over the surface of the Earth. This model is useful for predicting UWB interference power for terrestrial and airborne receivers.

A most important aspect of UWB devices involves their effect on existing receivers. ITS investigated this by introducing UWB signals into three different Federal radar receivers, as well as a much more detailed series of measurements on GPS systems. These tests are described on pages 14-15 of this technical progress report.

Recent Publication

W. Kissick, Ed., "The temporal and spectral characteristics of ultrawideband signals," NTIA Report 01-383, Jan. 2001. http://www.its.bldrdoc.gov/pub/ntia-rpt/01-383

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Effects of Ultrawideband Signals on GPS Receivers

Outputs

- Development of GPS/UWB compatibility test plan.
- Design and development of GPS laboratory, including control and data acquisition software and RF hardware.
- Results of tests on GPS receivers (to be completed in FY 2001).

In FY 2000, the Institute has investigated the general characteristics of ultrawideband (UWB) transmitters, with particular emphasis on how measured characteristics of UWB systems relate to interference to conventional radio systems. This general UWB effort is described in the preceding section (see pp. 12-13). In addition to the general UWB work, a separate project was established to investigate Global Positioning System (GPS) vulnerability to UWB interference, starting with the measurement techniques developed in the general UWB work. To accomplish this we monitored the behavior of several GPS receivers when exposed to various UWB signals in a controlled (i.e., conducting) environment. A secondary objective was to develop measurement methodologies to assess interference effects on the weak GPS signal. This work is expected to be finished in FY2001.

The Global Positioning System is a dual-use, space-based, broadcast-only, radio navigation satellite service that provides universal access to precise position, velocity, and time information on a continuous worldwide basis. The GPS constellation consists of twenty-four satellites that transmit an encrypted code, which is used by U.S. and allied military forces, and an unencrypted code, which is used in a myriad of commercial and consumer applications. GPS is presently used by aviation for en-route and non-precision approach landing phases of flight. Precision-approach runway incursion, and ground traffic management services are currently being developed. On our highways, GPS assists in route guidance, vehicle monitoring and identification, public safety and emergency response, resource management, collision avoidance, and transit command and control. Non-navigation applications may be grouped into geodesy and surveying; mapping, charting, and geographic information systems; geophysical; meteorological; and timing and frequency. Planned systems, such as Enhanced 911 (E911), personal location, and medical tracking devices are soon to be commercially available. The U.S. telecommunications and power distribution systems are also dependent upon GPS for network synchronization timing. In summary, GPS is a powerful enabling technology that has created new industries and new industrial practices fully dependent upon GPS signal reception. Given the importance of this critical government radiocommunication system, NTIA is concerned with the susceptibility of GPS to interference that can severely degrade the system. GPS vulnerability to conventional interference types (e.g., noise, continuous wave) is well documented; this work addresses interference from UWB signals.

In principle, an interference test is performed by applying a known amount of “foreign” signal to an operational radio system and noting any functional degradation in the radio performance. GPS interference testing includes the same basic elements, but the complexity of the system makes GPS testing quite different. The GPS operational system normally includes signals from multiple satellites, whose positions are constantly changing (including appearing and disappearing from view behind the Earth’s horizon). To maintain a repeatable test situation, a complex GPS simulator is used to provide a known and controllable sample of multiple GPS signals. These signals appear as though they had been transmitted from multiple moving satellites, but the simulated satellite positions can be reset to a selected standard configuration at the beginning of each test.

The typical GPS receiver provides some challenges also. The receiver usually does not exist as a piece of hardware with easily accessible test points, but rather is mostly software implemented on highly specialized ASICs and DSP chips. These programs process information from GPS signals, according to proprietary adaptive algorithms, and maintain a

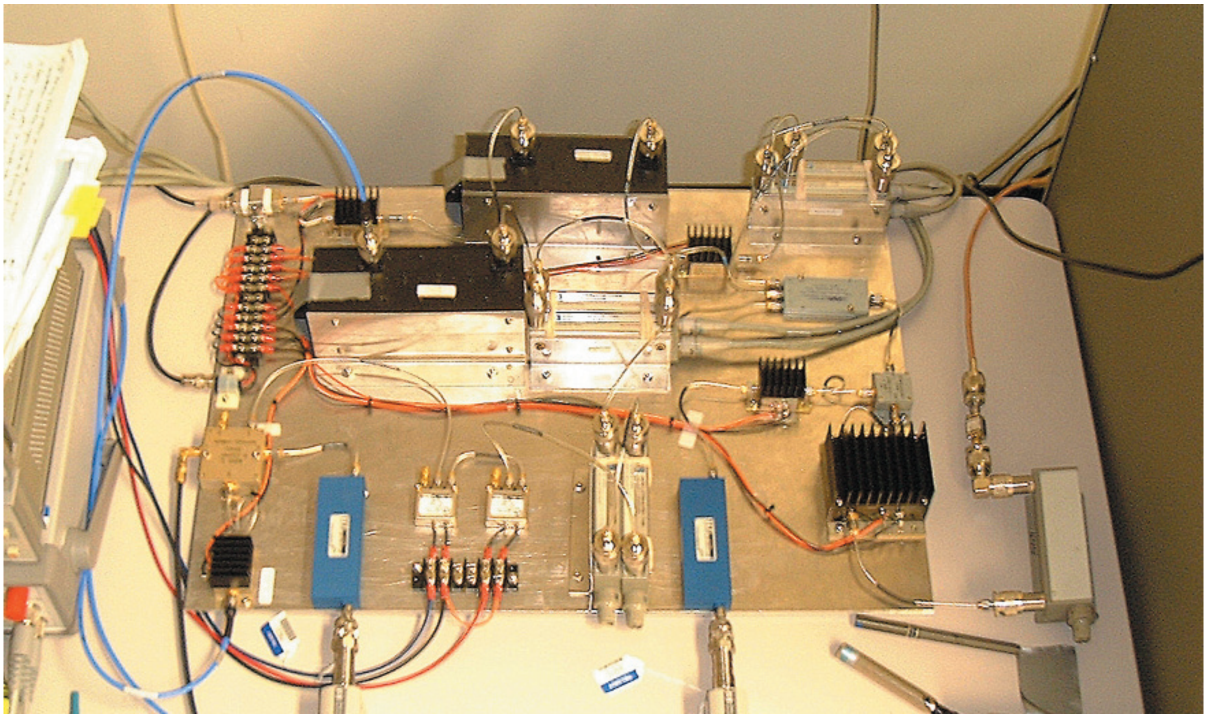

Figure 1. RF test fixture for GPS/UWB compatibility test (photograph by F.H. Sanders).

desired level of accuracy. Each different GPS receiver has its own functionality; therefore, each receiver may generate different failure modes from interference and may recover from interference in different ways. Finally, it is not obvious what measures should be used to identify unacceptable receiver degradation. Some GPS applications (e.g., surveying) require very high position accuracy. A cellular site requires high time accuracy. An aircraft application requires accurate position, velocity, and fast recovery from outages.

A collection of receivers was chosen for these tests which encompass a broad range of GPS technologies and applications (e.g., agriculture, surveying, aviation, public safety). Since we were unable to observe much of the internal workings of these receivers, we were limited to those results that were available outside the receivers. Given those limitations, we pursued our objectives with both radiated and conducted tests. The goal of the radiated tests was to measure the transfer function of each GPS antenna, including the phase linearity within the passband of a specific receiver. Conducted tests were divided into two parts: single-source and aggregate. In the single-source test, we were able to assess GPS susceptibility to a representative range of UWB signals. The aggregate tests will demonstrate how 2-6 UWB signals combine and what effect those signals will have on the chosen GPS receivers.

The basic GPS testing involves inserting an increasing level of UWB interference until a functioning GPS receiver loses lock on a given satellite signal. Having lost lock, the interference is decreased in various amounts, and the respective times until lock is reacquired are measured. In order to obtain high confidence in our results, a long simulation time is needed to completely measure each test point (i.e., approximately 45 minutes per interference level, for each UWB source, for each GPS receiver). Consequently the UWB/GPS test station is being run via computer control on a 24-hour/day basis.

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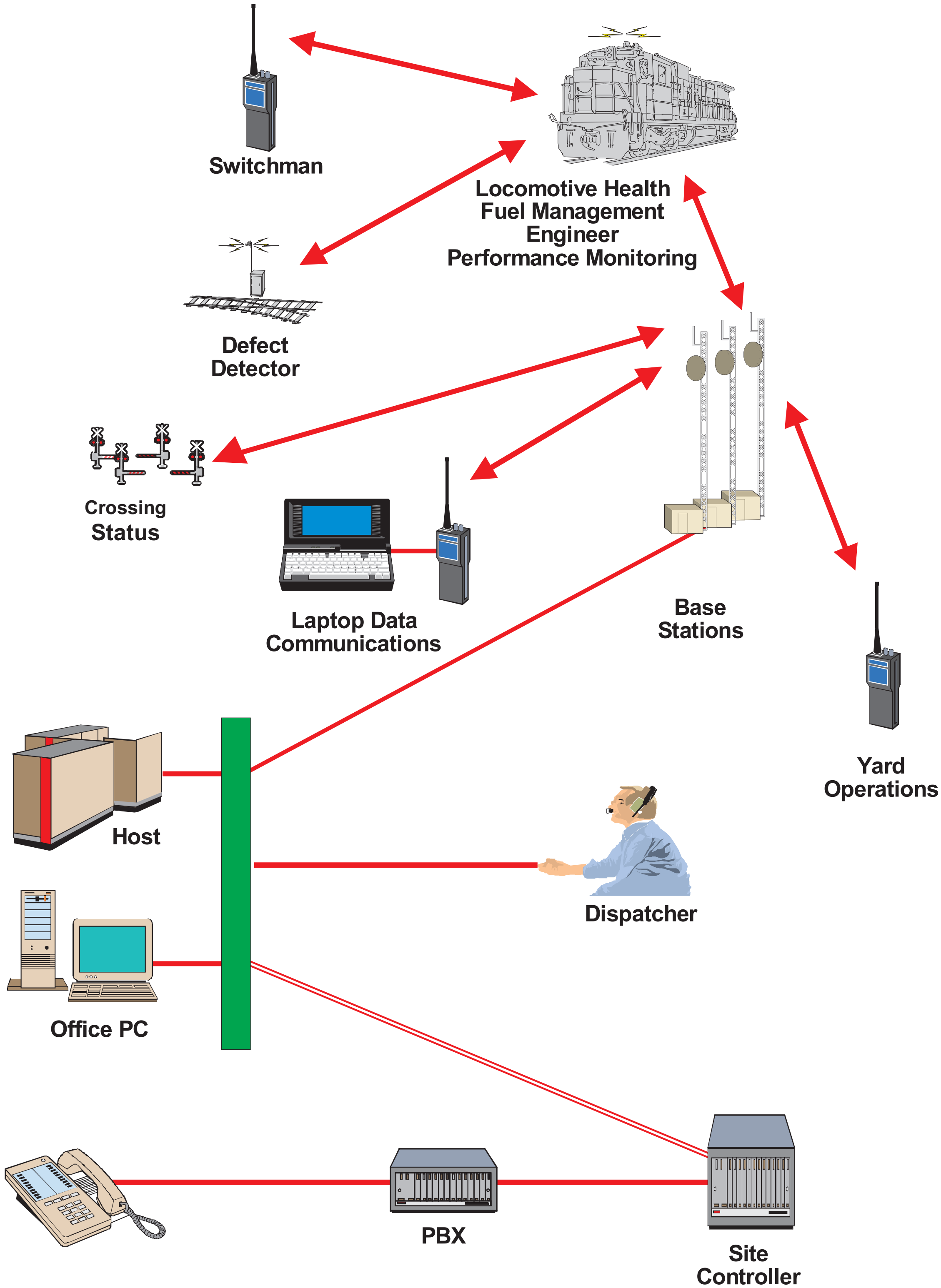

As part of the process involving network planning, analysis, or improvement actions, a thorough understanding of existing and future functional needs is developed. Typical elements of a railroad telecommunications network are outlined here. Red lines with arrows denote wireless communications; red lines without arrows denote wireline communications.