A Radio Spectrum Measurement System for Frequency Management Data

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Abstract—Since 1973, the U.S. Office of Telecommunications has been operating a Radio Spectrum Measurement System (RSMS) for the Office of Telecommunications Policy (OTP) in support of federal frequency management processes. The RSMS is a van-deployed computer-controlled receiving system designed to make many different types of measurements between 100 MHz and 12 GHz. The RSMS has been used in measurement programs on selected Federal Government communication and radar bands in many high spectrum usage areas in the Unites States. This paper discusses the capabilities of the RSMS van, and uses some measured data as examples of those capabilities.

I. INTRODUCTION

EFFECTIVE frequency management depends on knowing what systems are currently using the electromagnetic spectrum and what their characteristics are. Usually, most of these data come from frequency management records. In some cases, however, environmental measurements may be required to provide additional information. One major use of these measurements is to establish what sort of confidence may be placed in the accuracy of frequency management records and to show how the data in these records relate to the environment that a potential user would encounter. Radio spectrum usage, as distinct from assignments, is a particularly important type of frequency management data which is often obtained by environmental measurements. Measurements also provide data to be incorporated into models, operating standards, and frequency allocation decisions, and are used to test the accuracy of existing models and other prediction techniques.

The RSMS van was developed to provide useful data for the frequency management process [1]. Since the system was delivered in April 1973, the Office of Telecommunications (OT) has undertaken spectrum occupancy measurement programs in and around Washington, DC, Norfolk, VA, Los Angeles, CA, San Francisco, CA, and El Paso, TX, [2]-[4]. The primary objective in the communication measurements is to determine channel occupancy for each assignment and to correlate channel usage with assignment records. Several radar bands were also measured. The object in these measurements is to identify operating radars and measure their emission characteristics, comparing these observations with frequency assignments and operating standards. In addition, the RSMS has been extensively involved in collecting environmental data, emission characteristics, etc., and used in studies of several specific EMC problems, including the crowded 1030-MHz air traffic control radar beacon band and the 2700-2900-MHz radar band. Though the details of these data will not be discussed here, some samples of measured data are included as examples of the types of measurements the system routinely makes. Sections II through V discuss the RSMS characteristics and capabilities; Sections VI and VII give examples of environmental measurements and EMC studies in which the RSMS has had a major role.

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II. THE VEHICLE

The RSMS is installed in a modified motor home-type vehicle shown in Fig. 1. Copper screen was laminated into the fiberglass body for shielding, the suspension was reinforced, and strong points were provided to attach the antenna structures and racks. In addition to providing comfortable and convenient working space for men and equipment, the vehicle provides its own electrical power with two 5KVA generators (one for electronic equipment, one for air conditioning and heating). A mobile telephone and a hinged tower to support the main antenna arrays are also part of the van. Gross weight of the system is 17 300 lb with normal equipment and fuel.

III. ANTENNAS

The RSMS contains omnidirectional discone and biconical antennas covering the 30 MHz to 12 GHz range. Quadrant coverage is provided by sets of 4 conical helix antennas (150 MHz-4 GHz) and cavity-backed spiral antennas (1-12 GHz). Directional coverage (1-12 GHz)—useful for direction finding and isolating a signal for more detailed analysis—is provided by a 36-in dish antenna. A network of RF relays allows antenna selection via computer programs. Broad band noise diodes are located several places in the antenna system for automatic calibration of signal amplitude at the antenna terminals.

IV. THE RECEIVER

The RSMS is based on a Hewlett-Packard 8580 automatic spectrum analyzer system [5], augmented with antennas, specialized equipment for communication and radar measurements, and additional software routines. The major part of the RSMS is contained in three racks shown in Fig. 2. The receiver occupies most of the left and middle racks; the computer and interactive graphics terminal are contained in the right-hand rack. The 9-track tape unit, the transient digitizer, the pulse blanking system, and other equipment is contained in a 2-bay rack not shown. A block diagram of the RF/video portion of the RSMS is shown in Fig. 3. All of the instruments shown in the block diagram except those labeled with "*" are capable

Fig. 1. Exterior view of OT Radio Spectrum Measurement System.

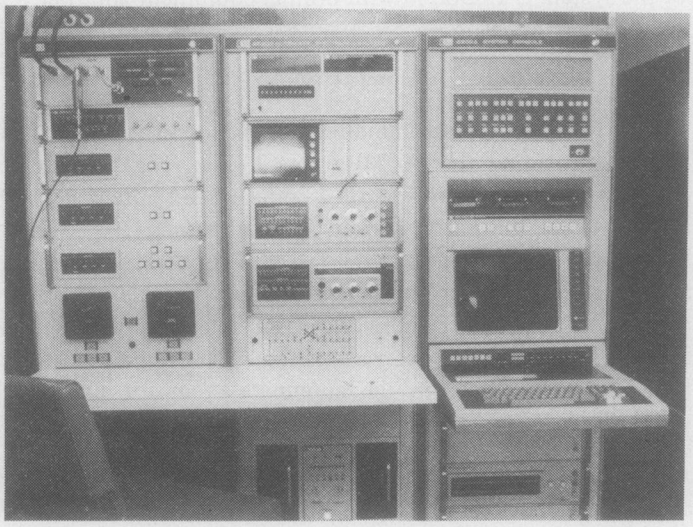

Fig. 2. Interior view of OT Radio Spectrum Measurement System.

of being controlled by the computer, functioning automatically by computer programs.

Receiver Input

An input switching unit can choose signals from the antennas or one of several calibration sources. A 0–70-dB input attenuator can reduce system sensitivity in 10-dB steps as necessary for strong signals. Preamplifier/preselector units are used to increase sensitivity and reject off-frequency signals. For frequencies above 500 MHz, a typical preselector consists

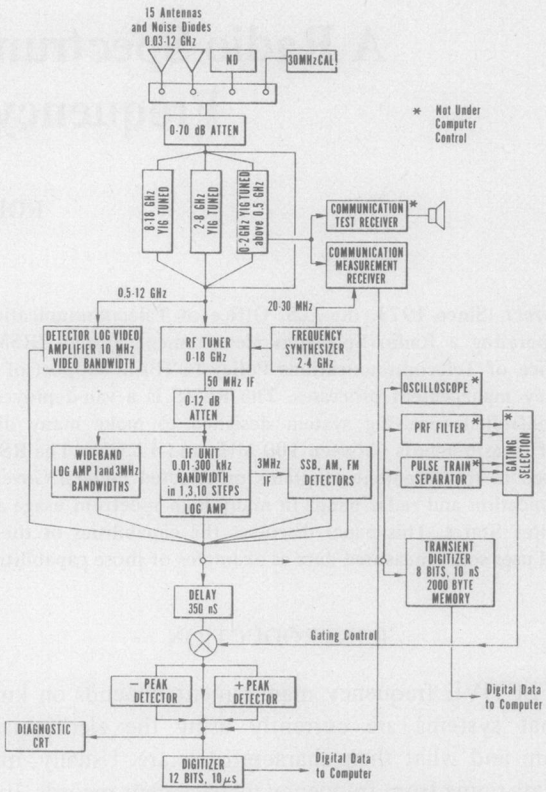

Fig. 3. RF/video block diagram of RSMS van.

of 2 stages of tracking YIG preselection, followed by a low-noise amplifier, followed by another 2 stages of YIG postselection. Fixed-tuned coaxial bandpass filters are used to isolate particular bands of interest below 500 MHz. A portion of the preamplified signal in the 5–500-MHz range is directed to a wide dynamic range communication measurement receiver and a manually tunable test receiver. The manually tuned communication test receiver enables an operator to monitor individual signals while the rest of the system continues scanning.

RF Tuning and IF Processing

The system tuning is controlled by a frequency synthesizer which allows very accurate system tuning—typically 2 parts in 10^7 for frequencies above 2 GHz. Several IF/detector units are used for various types of measurements. The narrow band IF unit allows a choice of 10 bandwidths between 0.01 and 300 kHz, in 1:3:10 steps. A 16-kHz bandwidth filter with very steep skirts is also available and is generally used for communication studies. Connected to this unit is a set of AM, FM, and SSB detectors to demodulate signals, as well as a logarithmic amplifier for amplitude measurements. The FM discriminators are dc-coupled so that frequency deviation or average center frequency of a narrow-band signal can be directly measured. A parallel wide band system provides a logarithmic amplifier output with 1- and 3-MHz bandwidths. Video bandwidths in excess of 10 MHz are available from a detector/log amplifier module driven directly from the preamplifiers. In this mode, the RF bandwidth of the system is determined by the selectivity of the YIG preselectors at the frequency of interest. Any one of these outputs can be selected for measurement by the rest of the system.

Pulse Blanking

A pulse-blanking system is used to isolate a single radar out of a multiradar environment, so that measurements may be made on that radar only. A pulse train separator and pulse repetition frequency filter provide a means of determining exactly when the desired radar pulses are present. This equipment operates with a high-speed video switch to gate only the desired radar pulses into the measurement circuits. Fig. 6 from a later paragraph illustrates the effectiveness of pulse blanking.

Digitizers

A gated signal passes through a final processing section before it is digitized. Plus and minus peak detectors are used to hold pulse-type signals for measurement. The 12-bit digitizer allows signals to be digitized every 10 μs with a resolution of 0.025 dB. Although overall system accuracy is not nearly so good, this resolution (along with short-term gain stability) enhances the usefulness of the noise diodes for system calibration.

A second digitizer is used for very high speed measurements, e.g., to measure digitally the shape of a nominal 1-μs radar pulse. The transient digitizer can be operated as fast as one measurement every 10 μs. Although this device gives only 8-bit measurements, proper control of scale and offset on the digitizer can locate these 8 bits over a small portion of the system dynamic range, giving measurements to better than 0.1 dB.

V. COMPUTER/DATA PROCESSING

Hardware

The RF/video hardware is controlled and calibrated by the computer in Fig. 4. Most of the major instruments, including all of the interactive graphics terminal, are on a common two-way instrument bus system. This bus controls the instruments, accepts data and status from the instruments, and provides processed data and text for display and copying. The keyboard, control panel, and tracking ball (cursor) provide a means to interact with the particular measurement program being run by changing operating parameters from the keyboard and controlling program branching.

The HP 2100 computer operates with 16-bit words and 32K of core memory. Very flexible input/output peripheral devices greatly increase the productivity of the system. The 9-track magnetic tape operates under DMA and is used especially to record the billions of data points typically involved in measurements. The three digital cassette decks and the dual floppy discs are used extensively to store programs and data. The system also contains a thermal printer, which can be used to copy text, and a paper tape reader which can be used to input programs from paper tape.

Software

The system has been operated mainly in Basic. Although Basic is not as efficient as some other languages, it is very easy to work with. Programs are continually changed in the field, and the ease with which program changes are made and tested makes Basic an obvious choice. Although Basic runs slowly,

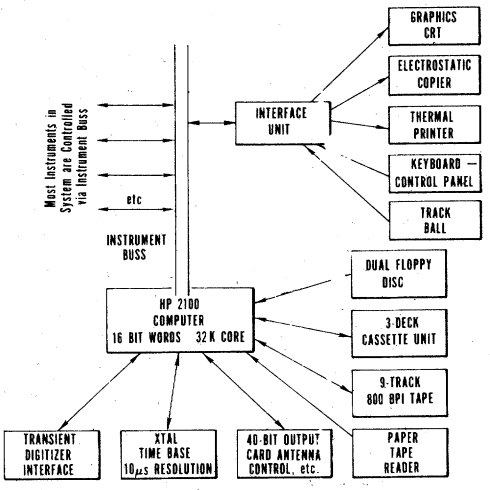

Fig. 4. Computer/data processing block diagram of RSMS van.

much of the computer time is spent waiting for measurement hardware to finish a particular task, and speeding up the software would not appreciably speed up overall system operation. When subroutines are encountered where software speed is crucial, a special subroutine may be created which is callable in Basic.

The feature of programmable hardware gives an increase in the hardware's utility. The computer enables the hardware to be automatically and rapidly calibrated. These calibration factors may be used to give results which could otherwise be measured only with hardware having much greater linearity and stability. At the same time, these calibration factors give clues which are useful in diagnosing long-time changes in system performance. Under computer control, many measurements may be made much more rapidly than before, with unbiased repeatability. Processed data may be displayed in a manner that is immediately useful to control the course of further measurements. This processed data can be well documented and labeled for immediate reporting and backed up by a magnetic tape duplicate which can be further analyzed if required. The ability of the software to operate the system in many different modes allows the same hardware to be used for widely differing measurements in the few seconds required to load a new program.

VI. EXAMPLES OF OPERATIONAL MEASUREMENTS

Calibration Routines

The standard system noise test (Fig. 5) is made on a daily basis to monitor the system noise figure and gain stability over the 0–14-GHz range. This 2-min test involves measuring system noise at 60 frequencies in this range, with and without a 22-dB excess noise source at the system input. The solid line traces the system noise figure, while the dashed line gives a system gain correction factor. Variations of this program are used to calibrate the system over narrower frequency ranges at the terminals of the antenna selected for a measurement. Other automatic routines linearize the system at 30 MHz, generating correction factors so that any system configuration can be accurately calibrated.

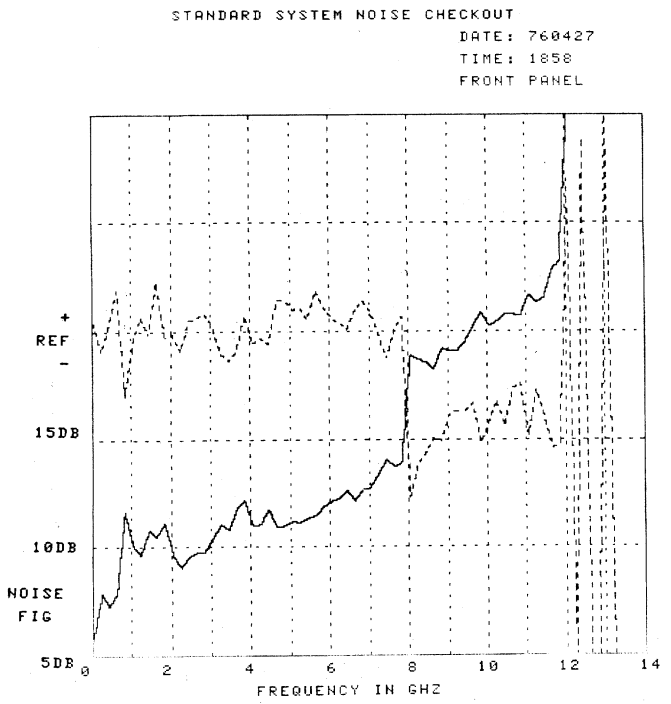

Fig. 5. Standard system noise test.

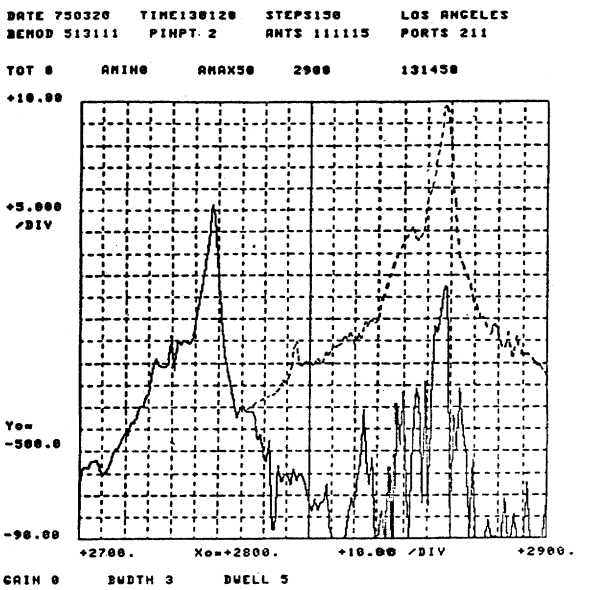

Fig. 6. Spectra of two radars. Right hand removed by blanking.

Communication Occupancy Measurements

Measurements of communication channel occupancy are made using the communication measurement receiver. This specialized hardware was designed to give the very high performance required for spurious-free measurements. Earlier measurements included many spurious signals resulting from receiver intermodulation and LO noise sidebands. The communication measurement receiver gives a 120-dB instantaneous measurement range with an 18-kHz bandwidth, while adjacent channels (25-kHz away) are suppressed 80 dB.

A typical communications measurement program includes a continuous scanning of the band of interest, stopping at each assignable frequency in the band (according to the band channelization plan). At each frequency, a burst of 40 measurements is made over an 0.8-ms period and processed to eliminate impulsive noise. The resulting single processed measurement is analyzed to give occupancy statistics at that frequency. If the signal is above an occupancy threshold amplitude, the channel is considered occupied. Statistics developed include percentage of time each channel is occupied, the average signal amplitude while the channel is occupied, and the maximum signal amplitude. This statistical data is updated as each channel is measured. About 7 ms is required to tune, measure, and analyze the data at each frequency; thus it requires about 3.6 s to measure each channel in a 500-channel band.

The accumulated statistical data is recorded on magnetic tape at the end of a 1-h measurement period. Statistical data from many 1-h blocks are combined into a single statistical file for a 1-week period and plotted and copied in a prescribed format. Data are also sorted by type of assignment and analyzed to show occupancy versus time of day and cumulative distributions of occupancy versus percentage of channels with that occupancy or greater.

Radar Spectra Measurements

Radar spectra are measured using the pulse-blanking circuits and the plus peak detector. The system is tuned in steps across the band of interest. At each frequency the peak detector holds on to the maximum signal of interest. With conventional rotating radar antennas, this maximum will occur when the radar antenna is aimed directly at the RSMS van. If the radar antenna rotates once every 5 s, the system must remain at each frequency for at least 5 s to ensure that the radar is pointed at the RSMS van sometime during the measurement period. Since the hardware peak detector output decays too rapidly to hold a signal accurately for a 5-s period, its output is sampled every 50 ms and the largest digitized value is held in memory. Thus the peak detector is a combination of hardware and software. This peak value is plotted on the graphics CRT as it is measured. The pulse blanker, described earlier, may be used to eliminate unwanted radars from the measurements. Fig. 6 shows a measurement of two radars. The dotted line shows the radar spectra as measured without pulse blanking. The solid line shows the measured spectra with the pulse blanker adjusted to reject the higher frequency radar. Note the effective rejection of about 40 dB.

Radar Antenna Patterns

Radar antenna patterns at 0° elevation angle are interesting to EMC engineers because they suggest the amount of sidelobe and backlobe antenna response available to couple interference between ground-based radars. Fig. 7 shows a radar antenna pattern measured as the radar rotates its pattern past the RSMS van. For these measurements, a burst of 500 points was measured, timed to begin slightly before one main beam passed and to end slightly after the succeeding mainbeam passed. The highest amplitude measurement in the first 250 data points is assigned an angle of 0°; the highest amplitude in the second 250 data points is called 360°; and the rest of the data points are scaled to fit between. In addition, the peak amplitude of the first mainbeam is assigned a value of 0 dB, and the rest of the pattern is normalized to this value. An

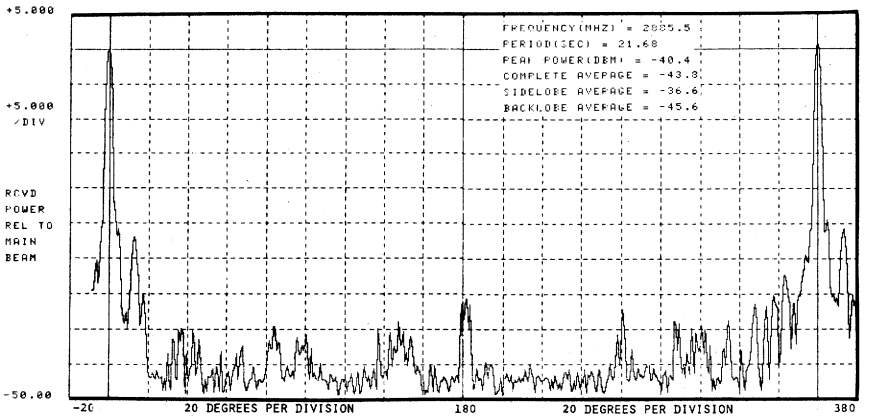

Fig. 7. Radar antenna pattern.

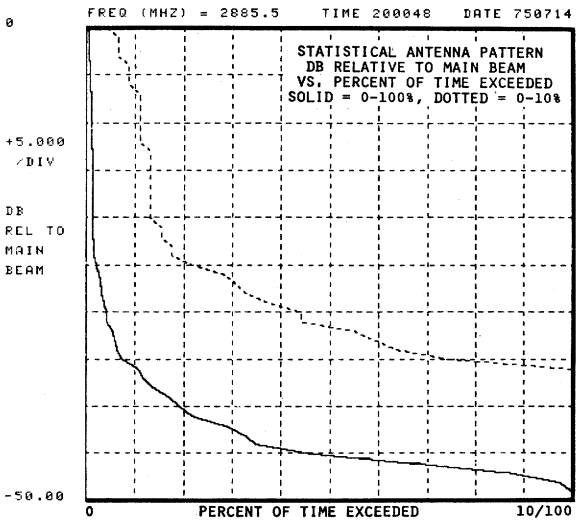

Fig. 8. Statistical radar output.

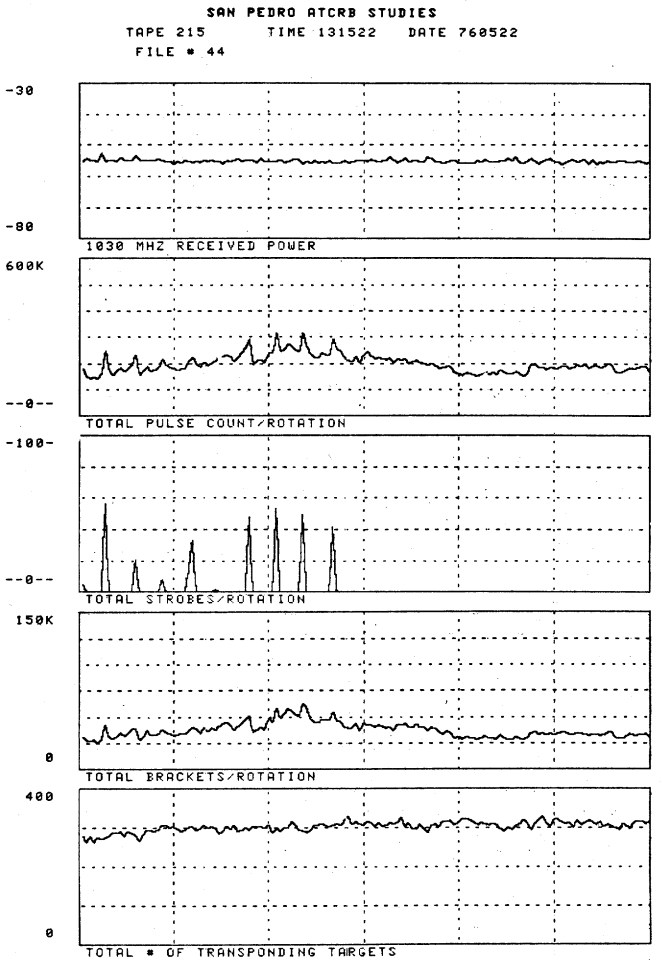

Fig. 9. RSMS measurement of ATCRBS performance.

accurate timer is used to time the antenna rotation period automatically to the nearest 10 ms. Various averages are calculated, including the average antenna gain in dB below mainbeam gain, averaging between 0 and 360°. The sidelobe average is similarly computed but uses only data within the range of 3 to 25° from the mainbeam. The backlobe average is taken from data points further than 25° from the mainbeam.

A statistical antenna pattern may also be plotted from the above data. In this case, all of the data points between 0 and 360° are ordered by amplitude and plotted as a cumulative distribution (Fig. 8).

VII. EMC ENVIRONMENTAL STUDIES

The mobility of the RSMS has been utilized to make measurements directed towards certain EMC problems where environmental measurements play a key role. A study was made of radar-to-radar interference in the crowded 2700–2900-MHz radar band. In the Los Angeles and San Francisco areas [6], the RSMS made measurements of the radar signal environments seen by radars which were victims of interference from other radars. Specific measurements were made on various component factors of the interference, including interferer emission spectra, interferer antenna gain pattern, propagation characteristics, victim radar antenna gain patterns, victim radar signal processing, etc. These data were analyzed to give a clearer understanding of which factors were most important in radar interference and were used to modify some of the existing EMC models. Eventually the data will be used in decisions in radar frequency allocations.

A study of the crowded 1030/1090 MHz Air Traffic Control Radar Beacon System (ATCRBS) was undertaken in the Los Angeles area. The RSMS was connected to the ATCRBS signal processor—the Common Digitizer (CD)—and was able to

monitor the CD while simultaneously making measurements on the 1030/1090-MHz signal environment. Specialized pulse processing hardware in the RSMS allowed many intermittant "problem signals" to be identified and related to particular system overload malfunctions on a real-time basis. Fig. 9 shows a partial set of graphs produced by the RSMS for a 30-min period. The top graph shows received signal power at 1030 or 1090 MHz, selected by PRF, interrogation modes, and direction of arrival. The lower 4 graphs show the CD response to the signal environment for a 12-s antenna rotation including total number of pulses received, number of strobes (indicative of system overload), bracket pairs received, and total number of transponding targets.

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A New State of the Art in EMC Field Measurement Instrumentation

P. C. MINOR AND L. E. WOOD

Abstract—**The U.S. Army, with engineering assistance from the U.S. Department of Commerce, has developed a powerful new tool which will significantly enhance the ability to ensure operational electromagnetic compatibility (EMC) among existing and planned communications facilities: the transportable, automated EMC measurement system (TAEMS). The TAEMS is a self-contained, self-propelled, air/ground transportable, fully automated measurement and analysis facility, designed to perform frequency and time domain measurements of the electromagnetic environment over the range of 20 Hz–40 GHz. Innovative system design features are discussed, and selected system performance characteristics are described.**

INTRODUCTION

Background

IN RECENT YEARS, the U.S. Army Communications Command, which has responsibilities for achieving and maintaining operational electromagnetic compatibility (EMC) among its communications facilities and other government (and nongovernment) spectrum users, has been faced with a significant backlog of EMC related tasks requiring field measurements and analyses. In attempting to cope with the field measurement workload, increasing in size and complexity and scattered worldwide, it became clear that the manually operated "suitcase" EMI receivers and spectrum analyzers being used were inadequate to meet all requirements. A twofold approach was proposed to eliminate the measurement deficiency: 1) upgrade and acquire additional manually operated equipment and 2) develop and deploy several fully automated mobile measurement systems [1]. The mobile automated systems would be relied upon as the primary measurement tool, with the upgraded manual equipment mainly utilized on quick-reaction tasks requiring limited data collection or when the automated systems were unavailable. The automated systems had to be readily adaptable to dissimilar measurement and analysis tasks including, for example, satellite earth terminal siting, investigating operational EMC problems plaguing Army airfields, and site surveying for electromagnetic radiation hazards to ordnance.

In early 1974, the U. S. Army undertook the development of what is now referred to as the transportable automated EMC measurement system (TAEMS). The U. S. Department of Commerce, Institute for Telecommunications Sciences (ITS) is assisting the Army in all phases of the effort, including formulation of the detailed system design, prototype development, system acquisition, integration and testing, new equipment training, and applications software development. At present, four field systems are being acquired by the Army with the

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