WIDE-BAND RADIO FREQUENCY (RF) SOURCE SURVEILLANCE

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ABSTRACT

Reduction in available radio frequency (RF) spectrum for use in aircraft testing has steadily increased the probability of interference. The increase in users and required bandwidth generates requirements for increased monitoring and active management of the RF spectrum. The detection of background RF emissions and monitoring of authorized users will be used by future range test engineers to make decisions on when and where to conduct test missions to minimize the probability of interference. The detection of authorized users exceeding their allotted RF spectrum as well as unknown emitters should include: the general geographic area of potential interference, and times of transmission.

This paper outlines the development of a complete system for wide-band RF monitoring to identify and locate active emissions. The RF surveillance system proposed must be inexpensive, easy to maintain, support large area coverage, and monitor wide bandwidths at long range. The system should contain software for emitter identification, which will determine where the current background and authorized RF transmissions occur and how they might effect authorized transmissions, and specialized software to alert spectrum managers of potential interference scenarios in real time based upon the daily schedule.

KEY WORDS

Spectrum Reallocation, Automated RF Monitoring, RF Detection, RF Tracking, Spectrum Management

INTRODUCTION

A combination of increases in the quantity of data required for testing aircraft and the reduction in the available RF spectrum for use in ground to air testing has increased the probability of interference between users. Currently, telemetry transmission for aircraft, missile, and uninhabited aerial vehicle (UAV) tests uses the L-band (1,435-1,535 MHz) and upper S-band (2,200-2,300 MHz, 2,310-2,390 MHz). Spectrum available for test and evaluation use is decreasing due to the frequency reallocation by the U. S. Congress for civilian use. A system is currently in place to schedule spectrum that is assigned to test facilities. Its purpose is to try to reduce interference between users. The Western Area Frequency Coordinator, located at Pt. Mugu, California, continually manages the assigned spectrum using schedules and basic deconfliction software along with prioritization. This system, however, can only react to the requirements and conflicts by the known users on the schedule. The system cannot react to known users exceeding assigned limits or unknown users. A system to schedule the requirements and avoid conflict is necessary. Figure 1 shows the use of available telemetry spectrum at Edwards AFB, California, through the year 2005. It is clear that spectrum management advances are necessary in scheduling and use to accomplish future test requirements.

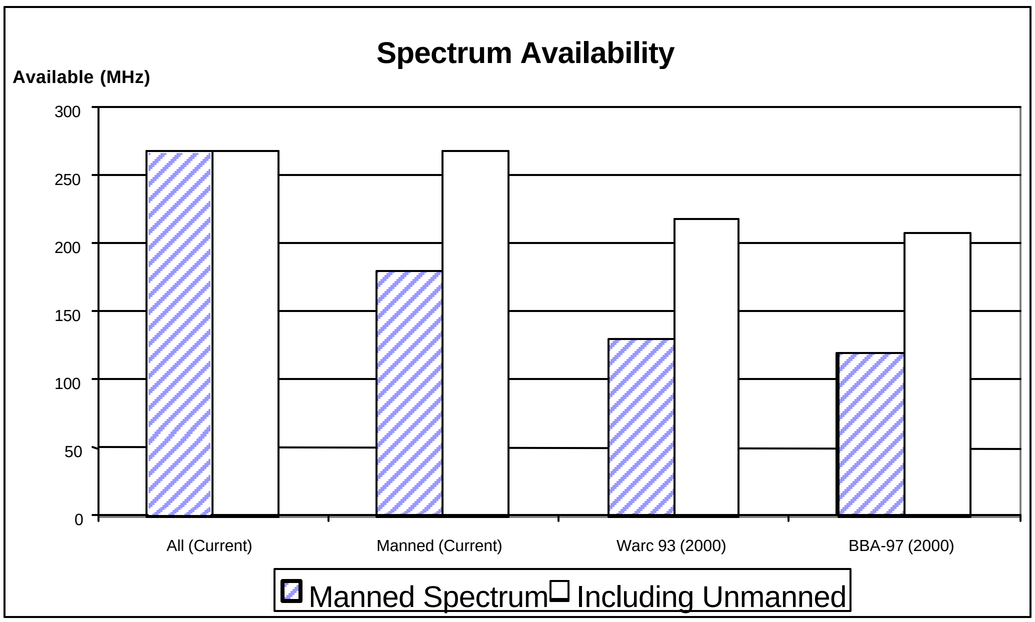

Figure 1: Current and projected future use of RF spectrum for test and evaluation at Edwards AFB, CA. Spectrum needs increase with advanced avionics systems data requirements at the same time as the available spectrum for test and evaluation decreases due to U.S. Congress reallocation.

The expanding use of the frequency spectrum and increasing bandwidths within a decreasing frequency band is driving a need for an increase in monitoring of the usable RF spectrum. It is becoming apparent that the detection of ‘on the air’ spectrum use will become a requirement for spectrum managers to maintain an interference-free environment. Currently program spectrum use is scheduled via an elaborate intrarange deconfliction system. This deconfliction process can be very difficult to accomplish without an accurate picture of the frequencies available for use, and the potential interference that currently exists, authorized or otherwise. In the near future, advanced avionics systems tests will be accessing common and ever shrinking spectrum. Test ranges in the Western Test Range are located in common geographical areas, increasing the potential for conflict. Information gathered by spectrum monitoring systems will be required by spectrum management and range test engineers to support decisions on when and where to perform test missions to minimize these conflicts.

DISCUSSION

Since 1992, the frequency spectrum in the United States and the world has gone through many changes. Driven by advances in electronics and computers, today's technological revolution is demanding access to larger amounts of spectral real estate than were ever previously available to the general public. In the past 5 years the federal government has turned 305 MHz of frequency spectrum over to the Federal Communications Commission (FCC) for auction to support these new ideas and technology. Of the spectrum reallocated, 205 MHz of this spectrum has been below 3 GHz and of that 126 MHz or 61 percent (Figure 1) are currently used in direct support of the test community. This is being done due to the fact that the spectrum used in test support does not meet the requirements necessary to be excluded for consideration of reallocation. In fact quite the opposite is true, spectrum used for test support is ideal for reallocation. The established band selection criteria and the current trend in spectrum reallocation sends a clear message to the test community. That is, without tactical significance or national security utilization we can expect future spectrum reallocation efforts to look to the test community to supply the spectrum.

The telemetry bands are not the only part of the frequency spectrum reallocated that has a major impact on the test community. The reallocation of the bands between 1,385 to 1,435 MHz have rendered the advanced range data link (ARDs/RAJPO) almost useless. This data link is used in flight test for precision time space position information (TSPI) that is unavailable by any other means. Accurate TSPI is critical to all flight tests and is the fundamental premise upon which these flights are based. The remaining 35 MHz of spectrum available in the tuning range is heavily utilized which makes the availability of additional channels for system expansion virtually nonexistent. Estimates for moving the link are in the range of $25M to $40M, but there is no suitable portion of the frequency spectrum available to move the link into. An attempt has been made to preserve the link for 10 years around the 23 ranges that currently use this device. Unfortunately, these protected sites are only protected for an 80 to 160 Km radius around the center point of the test ranges. Even the 160-Km radius is barely sufficient to operate the link for 8 minutes at 600 knots and does not account for the 400-Km line of sight distance if operated at 30,000 feet AGL. Although the effort to preserve the link at the current 23 operating locations is greatly appreciated, these restrictions are going to be difficult if not impossible to operationally manage.

Spectrum reallocation was not over on 1 January 1998 when the final report for the current reallocation effort was due. The apparent success of the FCC's recent license auctions and the nearly $8B in fees that have been collected will surely spawn further forays into government territory for additional spectral real estate. In addition to the perceived success of the FCC auctions, the Consumer Electronics Manufacturers Association (CEMA) is still attempting to push wireless communications services (WCS) and digital audio radio services (DARS) into the heart of L-band (1,452 to 1,492 MHz). Working in their favor, several other countries have launched satellites to provide DARS services in L-band. Congress and the FCC have authorized AsiaStar and AfriStar satellites (as part of the WorldSpace system) because the antenna coverage area does not pose a threat to telemetry in the United States. Closer to home, CaribStar satellite will definitely affect flight test telemetry. Their applications have been blocked due to the high potential for interference, but we cannot expect to hold off the entire world forever. If the current trend in band continues, in the next round of spectrum reallocation the test community can expect to lose additional spectrum.

If the test community expects to survive these reallocation efforts, comprehensive monitoring of the RF spectrum will be required. Monitoring will be needed to ensure efficient use of the spectrum resources and to determine potential interference scenarios. The reduction of usable spectrum for testing, increasing bandwidth demand of advanced avionics systems (telemetry data and video streams exceeding 5 Mb/sec), schedule changes and delays, and the large geographical area used for advanced aircraft testing all contribute to the difficulty of managing the available frequency spectrum. Frequency managers and range schedulers currently rely on multiple databases, software programs, and personal experience to adequately deconflict program spectrum requirements to minimize interference.

Flight testing of advanced avionics and electronic warfare (EW) systems requires spectrum characterization. This spectral identification takes two forms: to monitor the planned mission emissions to perform an independent conformation of test events; and to monitor unplanned emissions that may corrupt the test scenario. The identification of known and unknown signals is necessary to understand the operation of modern avionics systems. Modern systems are 'smart' in that they can independently react to the spectrum environment making traditional test methods obsolete. Test of these new smart systems will require comprehensive characterization of the environment in which they are tested so that the test engineer can understand why the system reacted to the environmental stimulus in a particular manner.

The ability to deconflict and monitor emitters in real time also relies on a database that has to be complete, easily accessible, and up to date on emitter types and characterizations. Emitter databases often contain obsolete waveform parametrics and emitters can drift from operational specifications, limiting identification. Multiple emitters may overlap and require additional processing for identification. Increasing amounts of test missions of advanced avionics systems like the X-33 do not remain at one base but cross multiple bases and areas of commercial activity. The RF spectrum data collected by the surveillance system must be immediately available, in near real time, to identify areas where data may be potentially lost due to interference. Therefore, an intelligent system must be in place to use the data in near real time to identify emitters, their location and power, and any possible frequency interference scenarios.

Some of the ranges currently have systems designed to monitor the RF environment to resolve interference and monitor EW test and training scenarios. The RF location/detection systems are currently used to characterize the RF environment for testing and are sometimes used in combination with emission simulators. The RF location/detection systems are also used in EW for location and jamming of enemy RF emitters. A variety of equipment currently being used and evaluated could form the basis of a future surveillance system. A brief description of these current technologies is contained below.

Current RF Surveillance Systems

The Mobile Threat Evaluation System (MOTES) [1] is an RF receiving system used on the range at Edwards AFB designed to measure signal characteristics during EW tests and exercises. The MOTES is capable of collecting measurements in the 0.1 GHz to 18.0 GHz range and identifying emitter signal parameters. Information can be provided in real-time and postanalysis with recording of all instruments aboard the MOTES system. The Multiple Threat Emitter Simulator (MUTES), along with the MOTES, is used to enhance the threat scenarios at Edwards AFB. Table 1 lists the MUTES/MOTES capabilities.

Condor Systems (San Jose, California) produces a line of equipment developed for the Advanced Carry-On Electronic ELINT/ESM System (ACES) [2]. The ACES is a fully automated ELINT/ESM system which combines long range signal detection, high probability of intercept, fine grain parameter measurement and complex signal handling in both the microwave and (optionally) the millimeter frequency range.

Table 1: The Multiple Threat Emitter Simulator (MUTES) was designed to simulate a variety of radar signals, and the Mobile Threat Evaluation System (MOTES) is a radio frequency receiving system designed to measure signal characteristics during electronic warfare tests.

MUTES/MOTES CAPABILITIES	
MOTES	MUTES
IFF Tracking aided assisted by Optics Collects 0.1 - 18.0 GHz Signals Measures frequency modulation characteristics Measures velocity countermeasure characteristics Measures signal power, bandwidth center frequency Measures amplitude modulation characteristics Measures pulse modulation and scan characteristics Mobile	IFF Tracking assisted by optics 120 Signals Preprogrammed Simulates SAM, AAA, EW, TA, and AI systems Simulates 10 preprogrammed threat families Five simultaneous signals Modifiable signal parameters

NOTES:
1. SAM Surface To Air Missile
2. AAA Anti Aircraft Artillery

The ACES system provides the capability to conduct a RF spectrum search scenario, collect waveform parametrics, resolve these parametrics against a user defined emitter library, and report active emitter transmissions to the operator. Signals not resolved by the emitter library generate a generic Active Emitter Report (AER). Multiple receivers are capable of performing a Time Difference of Arrival (TDoA) to geo-locate the transmitter. Signals captured by a directional antenna can be resolved to determine a Line of Bearing (LoB) to the contact. With both emitter identification and position, an effective tool for managing RF spectrum is available. The ACES system specifications include 0.5 to 18 GHz (optional to 40 GHz) coverage; 500 MHz of instantaneous bandwidth; programmable emitter library containing up to 4,000 emitter modes (optionally to 10,000).

Hardware/Algorithms/Database used for Emitter Characterization

Currently there are several databases available for use in the characterization of emitters. The databases in use are incomplete, inadequate, and are not connected. Currently there are several groups collecting data to try to develop a more complete database. This is an ongoing effort.

Current Data Tools for RF Spectrum Management

There are several spectrum management tools available for maintaining and updating Spectrum Management records.

Joint Spectrum Management Software (JSMSWIN Jay Sims for Windows). Used by the Army and Air Force, this software is a comprehensive set of tools for the base level frequency manager to maintain his/her frequency database, perform basic link analysis, interference analysis, and engineering analysis. It is written and maintained by the Joint Spectrum Center in Annapolis, MD., and is available for free to any government spectrum manager. The database is updated via the Government Master File (GMF CD) by extracting pertinent data and uploading into the JSMSWIN on a monthly basis.

The Automated Spectrum Planning, Engineering, Coordination, and Tracking System (ASPECTS). is used by the Navy and is basically the Navy version of the JSMSWIN product except that it has predefined frequency requirements for every Navy ship. This feature makes it relatively easy for a Navy spectrum manager to buildup the communications requirements for his area.

Spectrum 21. The follow on to JSMSWIN, it is 80 percent identical to JSMSWIN. The major difference is in its maximum database size, structure and network capabilities. Spectrum 21's database is much more robust and can handle a much larger database. It also uses a SIPR net (classified internet) connection to maintain database updates.

The Joint Terrain Analysis Program (JTAP). A propagation analysis tool developed by SENTEL Corporation, using the Terrain Integrated Rough Earth Model (TIREM) developed by the National Telecommunications and Information Administration. JTAP is used to predict radio coverage in a geographic area using DTED data from the National Imagery and Mapping Agency (NIMA).

RF Systems Research and Development

The detection, locating, and monitoring of planned and unplanned emitters is valuable information for frequency managers, flight test engineers, command and control systems, and for other military purposes. The emitters must be characterized effectively and in real-time situations to provide useful information. Most emitter and area RF characterization occurs after the test is completed. Software (complete databases) and hardware solutions need to be combined to adequately characterize the test or battlefield environment. A specially developed software system must be realized to alert spectrum managers of potential interference scenarios in real time based upon the daily schedule. The system should also be able to access a database of past scheduling as well as a current daily schedule of authorized users for information collection. The proposed system needs to compare the database with current use and identify authorized emitters, any unknown emitters, and potential interference scenarios using intelligent computation and processing in real time.

SOLUTION

To ensure that the spectrum remaining for access to government users is properly and fully used it will be necessary to maintain strict control of those signals allowed operations in a given area. In order to maintain this control it will be necessary to continuously monitor or 'police' the spectrum to guarantee that programs do not cause interference to each other. Monitoring of the spectrum can be a very complex and nearly impossible task. For this requirement we will only monitor the three telemetry bands (L, S, and upper S-bands) for center frequency, signal bandwidth, and time of occurrence. With this data it will be a simple task to check scheduled mission data and ensure that programs are operating within their assigned operating parameters (i.e., time, frequency, signal bandwidth).

There are basically two different types of collection systems that are capable of providing the required data for this purpose. The first is a receiver-based system, and the second is a spectrum analyzer-based system. Receiver-based systems provide fast scanning with high probability of intercept for highly dynamic signal environments. They provide excellent amplitude, frequency, and time of intercept, but do not measure bandwidth easily. Spectrum analyzers measure frequency, bandwidth, and time of intercept very well, but are slow which decreases the probability of intercept dramatically. For the purposes of monitoring the telemetry spectrum where the environment changes very predictably and slowly, a spectrum analyzer-based system will work more than adequately.

Proposed System

For our system, we have chosen to use a Hewlett Packard model 8566B spectrum analyzer. The computer code necessary to make the system operate will work with little or no modification o n other Hewlett Packard analyzers. With the spectrum analyzer we will use a TECOM 1 to 4 GHz omni directional antenna, K&L preselector filter, and a MITEQ AFS-44 pre-amplifier to complete the system. This basic system with the addition of a GPIB capable computer will have more than enough capability to monitor and record the activity in the telemetry bands. The system configuration is shown in Figure 2.

The collection technique for this system will be to digitize spectrum analyzer trace data and read it into the computer where it will be processed for signal identification. The spectrum analyzer output data is a 1,000-point data array, which corresponds to received amplitude vs. frequency data that is displayed on the analyzer screen. Program goals will be to gather 50 data points for every 1 MHz of spectrum or 5,000 data points for L-band (1,435 to 1,535 MHz). The data from individual 1,000-point sweeps (20 MHz of spectrum per sweep) will be concatenated into one large array and processed as a whole. The trace array will be processed by simply examining each individual data point for power levels above a predetermined threshold. When the data exceeds this threshold (signal start) a

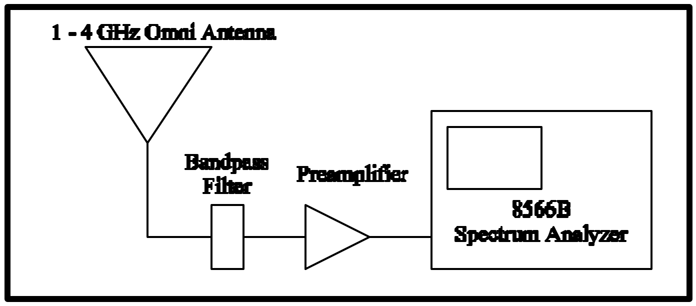

Figure 2: Proposed RF Detection System

counter will be started to count the number of data points until the signal drops below the threshold (signal stop). Once the number of data points have been counted the signal bandwidth (Bandwidth MHz = Number of data points * .02) can be measured. Center frequency can be determined by halving the bandwidth and adding it to the signal start assuming the signal is symmetrical. Additional frequency accuracy should not be required as telemetry transmitters always tune in increments of 500 KHz (except satellites and space vehicles). This coarse frequency measurement technique should yield results better than 100 KHz depending on the radiated signal bandwidth. Time will be added to an intercept from the computer system clock prior to writing the data to the signal's data file. This data file will be written out as ASCII text as frequency, bandwidth, and time of intercept to enable it to be read by most any windows-based processing tool such as Excel, or Access.

This configuration will yield a noise figure of 10 dB and should have a detection range of 4.6 Km for a 99 percent (-25 dBc) bandwidth measurement. This was found using the following equations:

$$R^2 = \frac{PtGtGrLt\lambda^2}{(4\pi)^2 \Pr}$$

$$\Pr = KTBrTsTb\frac{Br}{Bt}$$

Pt = Transmitter Power (5w)
Gt = Transmit antenna gain (0 dBil)
Lt = Transmitter cable / splitter losses (3 dB)
Gr = Gain of the receive antenna in direction of the desired transmitter (0 dBic)
K = 1.38X10-23 W/Hz/°K
T = 273° K
R = Distance to desired transmitter in meters
λ = Wavelength in meters
Bt = Transmitted signal bandwidth in Hz (typically 1 MHz)
Br = Receiving system bandwidth (100 KHz)
Ts = Signal Threshold above noise (10 dB)
Tb = Threshold for bandwidth measurement (25 dB)

Sweeping, digitizing, reading, and processing the five traces necessary to characterize L-band should take less than 20 seconds to complete. This, combined with the other two bands (S-band 2,200 to 2,300 MHz, and upper S-band 2,310 to 2,390 MHz), should allow all three bands to be sampled once a minute, which is more than adequate for this requirement.

Proposed System Cost

The total cost of the detection system hardware will be less than $100,000 per system. The software support for frequency deconfliction is under development. One proposed system will probably be sufficient for Edwards AFB to track aircraft spectrum usage and interference. The system will be setup for monitoring at the end of the flight line to easily gather data from every aircraft in use.

CONCLUSIONS

In the face of ever decreasing spectrum availability and increasing demands for data quantity and quality from the aircraft T&E community, spectrum management is presented with the goal to achieve more with less. To maximize the probability of achieving this goal, the need for actively managing spectrum use is necessary. Integrated and automated systems to schedule and monitor spectrum facilitate the proactive management of this valuable resource. Identifying and eliminating spectrum conflicts early in the T&E process reduces the cost and frustration of our customers. Future development should focus on computer software for the control of all the system components to facilitate near real-time data use, the development of an inclusive database of known emitters, and component cost. Increasing the distance of detection should also be addressed. As more users require spectrum, continued research into spectrally efficient modulation techniques and demand assignment multiple access-based systems become more important.

REFERENCES

[1] *Range Capabilities Handbook*, Edwards Air Force Base, California, 1996.
[2] *ACES*, Advanced Carry-On ELINT/ESM System, May 29, 1996, Condor Systems, Inc., San Jose, California.