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Measurement and Analysis of Urban Spectrum Usage

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To increase spectrum utilization, a thorough understanding is needed of its current usage profile. While some coarse information can be attained from spectrum licenses, essential details including the location of transmitters, transmitter output power and antenna type are often unknown. Additionally licenses do not specify how often the spectrum is being occupied if at all. Furthermore the local environment effects the propagation of radio waves; while this effect can be simulated, the results offer only moderate precision. Hence to categorize spectrum usage, measured data is vastly preferable to theoretical analysis.

This paper presents the results of measured spectra from 400 MHz to 6.4 GHz in urban Atlanta, GA USA. This study improved on past ones by resolving spectrum usage azimuthally, in polarization, and in time. The often-dynamic nature of spectrum usage necessitates the analysis of its usage over time. To provide accurate and substantive information on spectrum usage more then one billion data samples where taken. This data was analyzed to produce information on spectrum usage levels and characteristics. Additional analysis of the data was used to find low probability of intercept (LPI) signals in passive user bands. The information gathered from this study will be used to develop frequency agile radio protocols that maximize the amount of spectrum reused and lessen the possibility of inference.

Spectrum Study

To maximize the utility of the radio spectrum, knowledge of its current usage is beneficial. A spectrum study was initiated to provide multidimensional usage information and characteristics. This study improves upon past ones by resolving spectrum into nearly all its possible constituents. Figure 1 displays the dimensions that are assessed. For this paper only the urban location type (Atlanta) shown in figure 2 has been performed. Finally, to provide a statistically valid model of the spectral environment a large number of data samples where taken.

The implementation of this spectrum study is limited by the capabilities of measurement equipment. It is desirable to sense every emitted signal, but sensitivity is limited by receiver noise, intermodulation and also gain of the receiving antenna. Additionally the volume of data that the study produces it limited by the time it takes to perform the study. For a study to be statistically relevant enough must be collected. The volume of data measured is limited by the amount of time allocated for the study.

Spectrum Study Variables

- Frequency (400 MHz – 6.4 GHz)
- Time (short term usage)
- Time Period (6 discrete time periods per day)
- Polarization (Linear: Horizontal & Vertical)
- Azimuth (6 directions)
- Location type (Urban, Suburban, Rural)

Figure 1

Spectrum Measurement and Analysis System

This spectrum study required the design and construction of several hardware and software subsystems. Collection of the spectrum data required an antenna system (including an azimuthal positing system), an RF-subsystem, spectrum analyzer, and finally a data acquisition and control system, which is shown in figure 3. The mining of the data to produce

Atlanta Measurement Site

Figure 2

information is accomplished by several analysis programs.

Antenna System

A high gain antenna system was chosen to increase the system's sensitivity and to resolve spectrum the in azimuthal directions. Four antennas with 8 dBi to 9 dBi gain (depending on frequency) are able to cover from 100 MHz to 8 GHz with both linear polarizations (horizontal and vertical). The near constant gain over the frequency range of the antennas also provides close to constant beamwidth. These antennas are mounted on a rotating mast that offers good line-of-sight to the urban Atlanta area. Azimuthal positing is remotely controlled by the data acquisition and control system. Six azimuthal directions are used to azimuthally resolve spectrum and offer omni-directional sensitivity.

RF-Subsystem

Filtering and amplification is performed by the RF-subsystem. This system is connected to all the antennas and also serves as an antenna selector. A matrix of filters with an octave or less of bandwidth is used to reduce the creation of intermodulation in the subsequent stages of the system. After filtering, signals pass through a low noise amplifier (LNA) with a high (+27 dBm) third-order intercept point. The LNA is needed to lower the total systems noise temperature, since the spectrum analyzers has a very high noise figure (27 dB to 29 dB depending on frequency). Across the 400 MHz to 6.4 GHz frequency range, the total systems noise figure ranges from 6 dB to 7 dB. The filter and LNA combination results in an instantaneous spurious free dynamic range that is better than that for the spectrum analyzer. Hence, the spectrum analyzer limits the systems intermodulation performance and thus sensitivity.

As with all spectrum measurement system components the RF-subsystem is remotely controlled by the data acquisition and control system. All antenna and filter selection is verified by the used of position sensors and checked by software after any change in state. Additionally the RF-subsystem integrated a noise diode that is used to calibrate the complete RF system (except for the antennas and their short connecting cables). These features produce a highly reliable self calibrating system with built-in fault detection.

Data acquisition and control system

An automated system was developed to control the position of the antennas, choose the desired antenna and filter, perform calibration, and communicate with the spectrum analyzer. Another design requirement was very high reliability; this is needed for unattended multi-week data acquisitions. The system developed to meet these requirements incorporates fault detection and correction at all levels. Only a hardware failure can produce a fatal error, every other fault mode is accommodated. The complete spectrum measurement system has achieved better than 99.999% operational reliability. The only fatal error occurred as a result of an electromechanical microwave switch failure which was detected at the instant it failed. The system was able to identify the exact component which needed replacing. Additionally, the software keeps statistics on the health of each subsystem (to the component level for the RF-subsystem), recording the time and number of corrected fault events. This allows for the prediction and preventive replacement of components before they fail completely.

Spectrum Measurement System

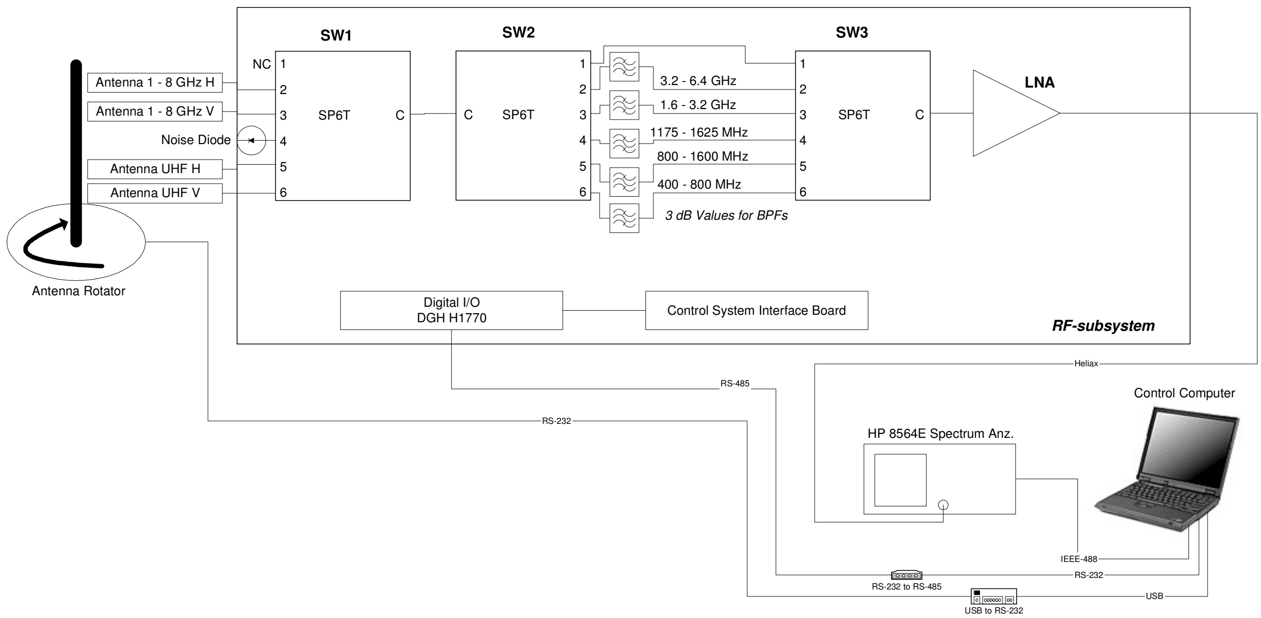

Figure 3

The data acquisition and control software integrates two operating modes: interactive and batch processing. The latter is used for multi-week unattended data acquisitions. A scheduling program was designed to minimize the time needed to perform multidimensional spectrum studies. All data is saved in a file as a collection of objects, with each object containing one sweep from the spectrum analyzer and 20 other essential parameters. This format retains all the data produced by the spectrum analyzer in its raw form, thus allowing for latter post-processing.

A modified scheduling program with more frequent measurements was employed to detect low probability of intercept (LPI) signals in passive user bands.

Analysis Software

The post-processing of raw collected data permits extensive data mining of the measured spectrum. First, the data is calibrated with the help of the noise diode and 6,000 data points for each 6 MHz frequency range (12,000 data points are used to calculate noise figure). Initial analysis software was developed to demonstrate the multidimensional usage of spectrum. Additional software is being developed to examine usage patterns in spectrum and determine other characteristics.

Results and Conclusion

More than 2 billion spectrum measurements were taken in urban Atlanta over several weeks. Figure 4 display initial analysis of the 1.2 GHz to 1.4 GHz range. These plots are just a few of the hundreds required to minimally describe Atlanta's spectral environment.

Because of the great wealth of information produced from the Atlanta spectrum study, only a minute fraction of it can be presented in print. Hence, the authors have decided to offer post-processed data in Excel format online: www.measuredspectrum.com. Additionally, interested parties can attain the complete Atlanta spectrum study in its raw data form. This data can be used to develop frequency agile protocols and assist in testing their ability to transparently use spectrum. Other interference analyses and spectrum utility maximizations are possible with the use of this rich data set.

The authors are in the process of performing a suburban spectrum study which will be followed by a rural study. These three studies will assist in classifying spectrum usage by location type.

Spectrum Measurement Dimensions for 1200 MHz to 1400 MHz

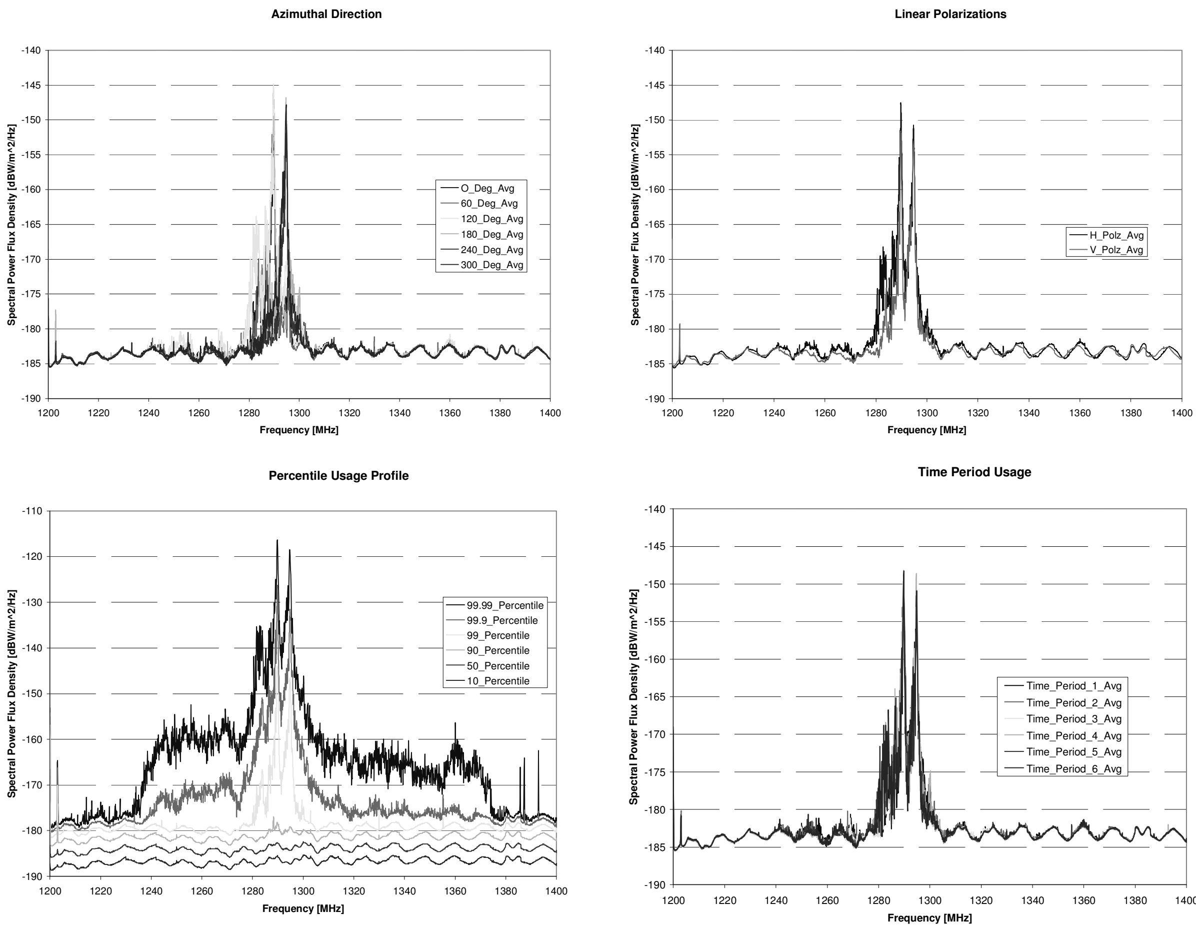

Figure 4