Southwestern Bell Technology Resources

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FEDERAL COMMUNICATIONS COMMISSION
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December 17, 1993

Dr. Thomas P. Stanley, Chief Engineer
Federal Communications Commission
2025 M Street, NW
Washington, DC 20554

Re: Southwestern Bell Technology Resources, Inc.
Call Sign KM2XBI
File Number: 3037-EX-PL-92
Quarterly Progress Report Number Six

Dear Dr. Stanley:

In accordance with the Federal Rules and Regulations Part 5, Section 5.204(b), attached please find the sixth quarterly progress report for Southwestern Bell Technology Resources, Inc. in connection with our personal/wireless communications testbed in St. Louis, Missouri.

Please direct any inquiries to me at 314-529-7567.

Sincerely,

John A. Moore
Director, Wireless Communications

Attachment

550 Maryville Centre Drive
St. Louis, Missouri 63141

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FEDERAL COMMUNICATIONS COMMISSION
OFFICE OF THE SECRETARY

FCC Quarterly Progress Report Number Six (6) in Connection with Personal/Wireless Communications Testbeds in St. Louis, Missouri

Conducted by Southwestern Bell Technology Resources, Inc.

December 17, 1993

Authorized by FCC Experimental License
Call Sign KM2XBI, File Number 3037-EX-PL-92

1.0 Introduction

The following report summarizes the results of tests and progress in the two areas of: Wireless Local Loop and In-Building Wireless Communications.

The tests reported here were conducted in and around Southwestern Bell Technology Resources' facilities in St. Louis, MO, under the experimental license granted to Southwestern Bell Technology Resources, Inc. (SBTR). For further information on SBC's view of PCS/PCN, and background on Wireless Drop and PBX/Centrex, please consult our first quarterly report filed with the FCC on September 19,1992.

2.0 Wireless Local Loop Progress

Since the last progress report, Southwestern Bell Telephone Company (SWBT) has executed a contract to obtain a radio system with which to field test wireless local loop. This equipment is based upon the Bellcore Wireless Access Communications System (WACS) version 0.1 specification[1]. In late September of this year, we received engineering prototype equipment and began testing in our Portable Communications Laboratory (PCL). Upon examination of the database of private point-to-point microwave operations in and around St. Louis, we selected the operating frequencies of 1975 MHz for the downlink (base station to subscriber unit) and 1925 MHz for the uplink. Initial emissions began on September 22, 1993 at powers no greater than 200 mW. All testing has been within our building with the exception of a brief outdoor test on 9/30/93.

2.1 Candidate Participants

A database of all the SBC employees was obtained and plotted on a map of St. Louis during 1992. From this plot, the area with the highest density of SBC employees was determined. This area is in west St. Louis County. Using the location database and the list of employees wishing to participate in the testbed, radio port locations were identified. A map of the testbed area with the radio port coverage identified is shown in Figure 2.1.1.

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[1]TR-INS-001313, "Generic Criteria for Version 0.1 Wireless Access Communications Systems (WACS)", Issue 1, October, 1993.

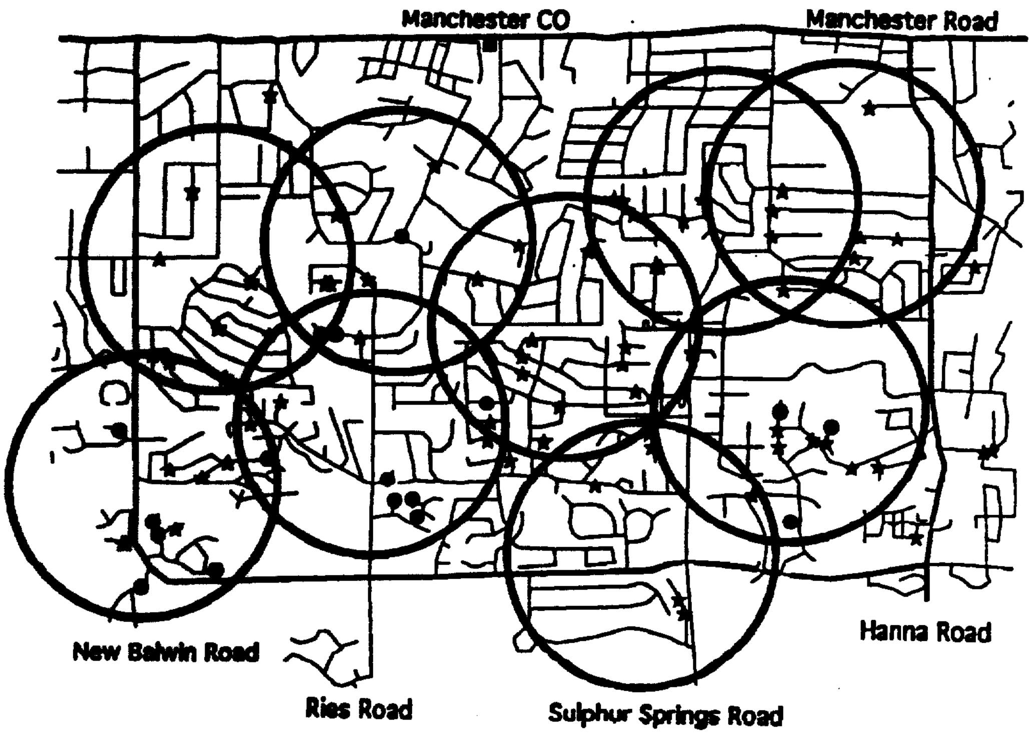

Figure 2.1.1 - Radio port coverage

2.2 Spectrum Availability and Propagation Analysis

SWBT outside plant engineering personnel are currently working out the facilities requirements and approach, using the telephone company facilities which currently exist in the testbed area. The testbed area was examined and tentative telephone/utility poles for radio port mounting were identified. To finalize the radio port locations requires that we perform propagation tests from the candidate port locations to the participants' homes to ensure that there will be adequate signal strength. In order to perform the propagation tests, and to operate the testbed, we must ensure that we do not interfere with existing private point-to-point microwave operations in the area. SBTR personnel made measurements in and around the testbed location to identify the presence of these microwave operations. We analyzed the data and determined which frequencies were available for our testing.

2.2.1 Spectrum Availability Study

Deployment of the wireless local loop testbed in the 1.9 GHz or 2.1 GHz frequency bands requires that the we share the available spectrum with OFS operators. To achieve this, operating frequencies of the wireless access systems must be carefully selected, or coordinated, to ensure that both 1) operational fixed services will not receive any harmful interference from the wireless local loop system transmissions, and 2) the wireless local loop system will not receive any harmful interference from operational fixed microwave transmissions.

The intent of this study was to examine the spectrum usage and frequency coordination in the 1.9 GHz and 2.1 GHz private OFS bands around the West St. Louis County testbed. This study carefully examines the potential of intersystem interference through direct measurement of the spectrum around the testbed. These measured spectrum traces are compared on a channel-by-channel basis against an OFS license database. Specific criteria, which include operating parameters for both the terrestrial microwave and the wireless local loop system, are applied in the comparison process to determine if a non-interference condition can be met (i.e., if a specific microwave channel is "available" for use), and analysis will be performed as specified by the FCC[2]. In deploying the wireless local loop system, suitable operating frequencies will be selected from the available microwave channels list developed by this study.

2.2.1.1 Description of the Study

Due to limited spectrum availability, spectrum sharing (frequency coordination) among terrestrial OFS operations is quite common. The Telecommunications Industry Association (TIA) working group 14.11 has developed a comprehensive set of interference criteria for OFS-to-OFS frequency coordination[3]. The prescribed TIA coordination procedures take advantage of common attributes of OFS links. In general, OFS links operate in a frequency division duplexed, point-to-point communication mode using a elevated antennas for a line-of-sight radio propagation link. Since it is a fixed, rather than a broadcast, service, specialized high-performance antennas can be used at either end of the link. These specialized antennas are typically high gain (> 25 dB), directional, reflector-type antennas with relatively low sidelobe levels and good cross-polarization discrimination characteristics.

By pointing the antennas in different directions, OFS links ensure that sufficient RF isolation[4] between co-channel antennas exists for shared use of a microwave channel. In high density areas where the combined effects of antenna directivity and signal propagation loss may not provide sufficient RF

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[2] Amendment of the Commission's Rules to Establish New Personal Communications Services, Second Report and Order, GEN Docket 90-314, RM-7140, RM-7175, RM-7618, October 22, 1993, pages 58-64.

[3] Telecommunications Industry Association Telecommunications Systems Bulletin 10-E "Interference Criteria for Microwave Systems,"

[4] RF isolation refers to the difference, in dB, between the effective isotropically radiated power of an OFS antenna and the received power at some arbitrary location. RF isolation is identical to path loss along the boresight of the OFS antenna.

isolation, co-channel links may operate with cross-polarized antennas so that a desired level of RF isolation can be achieved. This simple description of frequency coordination is, in essence, identical to the procedure outlined in EIA/TIA Bulletin TSB10-E. The bulletin provides specific criteria to determine the distances over which frequency coordination must occur with co-channel systems, the interference power level available at a microwave antenna site due to these co-channel systems, and the corresponding performance degradation the interfering power level can induce. Operating parameters of each OFS, including the antenna directivity and polarization, are considered in the coordination procedure.

Frequency coordination between OFS links and a wireless local loop system is quite different than the OFS-to-OFS case. Since wireless local loop systems support non-nomadic broadcast services, signal transmissions are not concentrated in a specific direction. This phenomenon alone makes spectrum sharing between OFS and wireless local loop services more difficult, but not entirely intractable. Unfortunately, additional problems do exist. Unlike OFS operations, wireless local loop systems will be deployed in residential, suburban, or dense urban areas using relatively low antenna heights (particularly at the fixed access units). The lower antenna heights and increased clutter along the propagation path gives rise to severe multipath propagation. Signal transmissions between the radio port and fixed access units are scattered (or redirected) and depolarized as they propagate to their receiving point. The redirection and depolarizations of the transmitted signal energy can occur in a random, and uncontrollable fashion, as it depends on both the characteristics of the terrain and the localized (human-made) clutter. Multipath propagation presents a particular difficulty in this type of frequency coordination because the attributes of the OFS link antennas, the directivity and polarization discrimination, no longer present any significant advantages.

To date, a reliable method for coordinating frequency use between operational fixed microwave and wireless access services does not exist. For the past months, the TIA TR-14.11 working group has been developing a set of criteria for this purpose, but the corresponding standard has yet to be released. Other technical and regulatory bodies have proposed frequency coordination techniques[5], but none of these techniques have been applied to a "real-world" application.

The difficulties in sharing spectrum in the multipath propagation environment has been carefully studied by Southwestern Bell Personal Communications (SBPC). This spectrum sharing study was conducted under SBPC's Experimental License for the development of Personal Communication Services in Houston, TX. As part of the study, the spectrum usage in the 1850 to 1990 MHz private operational fixed microwave band was

[5] Amendment of the Commission's Rules to Establish New Personal Communications Services, Second Report and Order, GEN Docket 90-314, RM-7140, RM-7175, RM-7618, October 22, 1993, pages 58-64.

examined through direct measurement of the spectrum. Two major findings of the study were:

- Multipath propagation has significant implications on spectrum sharing between terrestrial microwave and wireless access services. At ground level, regions of constant RF isolation are irregularly shaped and do not generally coincide with the radiation pattern of the microwave antenna. Factors such as terrain, building heights, and street orientation have an impact on the shape of these RF isolation regions.

- Mutual interference between terrestrial microwave and wireless access services can be minimized by a frequency coordination technique that employs both direct measurement of spectrum usage as well as theoretical models that compute the inference potential based on the measured data.

Based on these results, SBTR began a frequency coordination study for the wireless local loop testbed. On November 15, 1993, SBTR began performing receive-only outdoor signal measurements in the 1850 to 1990, 2130 to 2150, and 2180 to 2200 MHz bands around the testbed. For these measurements, a van outfitted with a custom spectrum measurement system canvassed the testbed periphery to provide a description of the microwave environment in and around the testbed. These measurements were necessary to obtain a rough indication of spectrum availability in the limited geographical area. Two sets of stationary measurements were taken at each location in order to reduce the probability of being in a fade. After the first set was completed, the measurement equipment was moved approximately three feet and the second set of data was recorded.

2.2.1.2 Measurement System

A diagram of the receiving equipment used for the outdoor measurements is shown in Figure 2.2.1.2.1. The heart of the measurement system is a spectrum analyzer controlled by a portable computer. A cascade of two low noise amplifiers (LNAs) placed in the path from the receive antennas to the spectrum analyzer serve to increase system sensitivity. A computer controllable variable attenuator separates the two LNAs, providing automatic attenuation in the presence of strong signals to increase the dynamic range of the measurement system. Two sets of antennas covering the 1850 to 1990 MHz and 2130 to 2200 MHz sub-bands can be linked to the measurement set by a switch located in front of the LNAs. Only one antenna is connected to the measurement set at a time, however. Measurement data is stored in the PC, along with location information collected by a Global Positioning System (GPS) receiver, not shown in the diagram. An uninterruptable power supply provides conditioned AC power to the spectrum analyzer and computer, while the GPS receiver is powered by a DC source. A more detailed description of the measurement equipment follows.

A portable personal computer is used to control measurements and store data to be processed and analyzed later. Interface with the LNA assembly and spectrum analyzer is via General Purpose Interface Bus (GPIB), and connection to the GPS receiver is through a serial port.

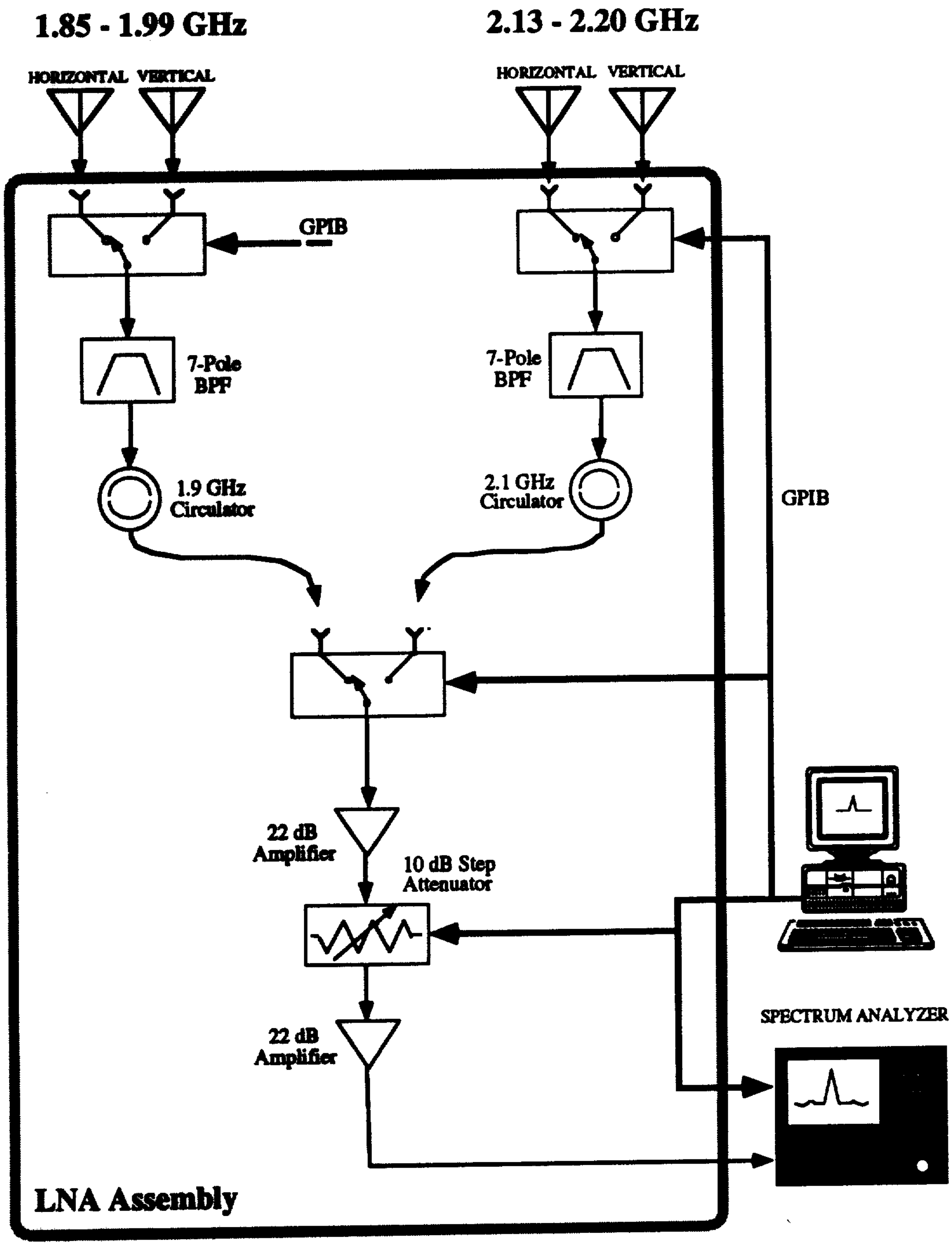

Figure 2.2.1.2.1. Measurement system configuration.

A low noise amplifier assembly is used to provide rejection of out of band signals and to establish the noise figure of the measurement equipment. The maximum input signal level that the equipment can tolerate is limited by the spurious performance of the spectrum analyzer. To improve the dynamic range of the measurement equipment, a variable attenuator is adjusted under software control to keep the peak signal level into the spectrum analyzer at less than -30 dBm. Although this procedure degrades the sensitivity under strong signal conditions, it prevents analyzer spurious responses from corrupting the signal power measurements.

With the attenuator set to 0 dB, the minimum discernible signal of the measurement equipment is approximately -117 dBm with a resolution bandwidth of 100 kHz. The corresponding spurious-free dynamic range is approximately 60 dB. To minimize the effects of the noise floor on the measurements, only signals above -107 dBm (signal-to-noise ratio ≥ 10 dB) are considered accurate. Thus, the measurement dynamic range at the minimum attenuator setting is 50 dB.

With the attenuator set to 10 dB, the dynamic range is approximately the same, however the sensitivity degrades by approximately 2 dB. Higher attenuation settings cause more severe degradation in sensitivity, but signals large enough to require these levels of attenuation were rarely encountered during actual field observations. Seven pole cavity-type bandpass filters provide selectivity for the two frequency bands of interest. A coaxial switch allows computer selection of the band to be measured. Horizontally or vertically polarized receive antennas can also be selected under computer control via coaxial switches.

Two omnidirectional antennas covering all three sub-bands were used in the measurements. One is vertically polarized and the other is horizontally polarized, and both antennas provide nominally 0 dBi gain with a voltage standing wave ratio (VSWR) of 1.5:1 maximum. The elevation plane beamwidth of the antennas is 35 degrees. Both antennas consist of a dipole array enclosed in a tubular radome and attached to a stainless steel base plate.

A six-channel GPS receiver provides position fixes to within 100 meters as microwave signal level measurements are recorded. The GPS receiver consists of a fixed-pattern antenna with preamplifier, a coaxial antenna cable, and a receiver processor unit. Latitude and longitude readings obtained from the GPS receiver approximately once every second are ported to the computer and used to tag the spectrum analyzer measurements in real-time. A 15 degree mask was placed on the GPS receiver satellite tracking function to increase the integrity of the position fixes. During those periods where fewer than three satellites were in view due to too few satellites in the constellation or obstructions in the path, GPS could not provide position information. If the loss of latitude and longitude data was temporary (on the order of seconds, as may occur while driving by a tall building), then the computer tagged the measurement data with the last position fix calculated by the GPS receiver. If, on the other hand, the lack of position information was more long-term, then either the measurements were delayed until GPS reception improved, or an alternate means of obtaining position information was used (recording street addresses, etc.).

For outdoor measurements, equipment is housed in a customized van. The antennas are bolted to a ground plane attached to the top of the van. Cable runs from the antennas were routed through a back window to the measurement set. The interior of the van with measurement equipment installed is shown in Figure 2.2.1.2.2. Most of the equipment inside the van is housed in two cabinets within easy reach of the measurement system operator.

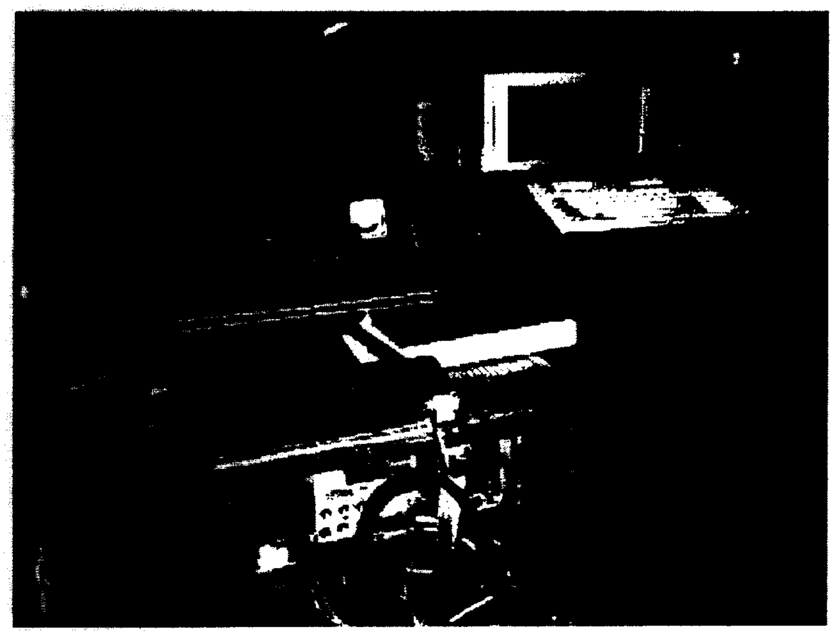

Figure 2.2.1.2.2. Van installation of measurement equipment.

2.2.1.3 Measurement Procedure

The following general procedure was used for the spectrum usage measurements. The measurement program resident on the portable computer was started, and a pre-defined configuration file was read by the program, based on the type of measurements to be conducted. Data from the configuration file initialized the measurement equipment with the correct band, antenna, and scan parameters. If the configuration file included the command to tag measurement data with location information obtained from the GPS receiver, then the computer informed the operator whether GPS position fixes were being obtained. The operator had the choice of whether to begin measurements without GPS or wait until a "GPS lock" verification was noted. A brief description of the drive route or stationary location at which measurements were to be taken was entered into the computer by the operator. When the van was in the correct location for measurements to begin, the operator initiated scans with a single keystroke on the computer. At the end of a measurement session, the recorded data was downloaded onto a centralized PC network for permanent storage.

2.2.1.4 Analysis Procedure and Preliminary Results

Although spectrum usage measurements have been conducted for both the 1.9 GHz and 2.1 GHz private operational fixed microwave bands, initial data analysis has concentrated on the 2.1 GHz band. The initial analysis has been conducted in two phases. For the first phase, a data base of 2.1 GHz OFS links operating in the St. Louis Metropolitan area was analyzed to assess the usage of the band on a licensing basis, and more specifically, to determine if any microwave links were located close the Wireless Local Loop testbed. In the second phase, the OFS database and actual spectrum usage measurements were used to compute the degree of RF isolation that exists between the testbed and each microwave link in the database. Test frequencies were selected from these results by comparing the RF isolation, the aggregate power level for the wireless local loop system (the scalar sum of radiated power levels for the radio ports and wireless fixed access units), and the maximum allowable interference level as set by TIA Bulletin TSB10-E.

The 2.1 GHz private OFS band is comprised of two 20 MHz segments, 2130 MHz to 2150 MHz and 2180 MHz to 2200 MHz, for either 50 MHz frequency division duplexed operation of two way microwave links or single frequency operation for one-way links. The two 20 MHz segments are further subdivided into twenty four 800 KHz channels with 400 KHz guard bands at the lower and upper ends of each segment. The maximum occupied OFS bandwidth for either analog or digital systems is 800 KHz. In practice, systems typically use digital modulation and have bandwidths of 200 KHz or 400 KHz. Operators of 2.1 GHz OFS links, which include railroad companies and public utilities, use microwave communications systems for reliable, low-cost, and usually low data rate, telemetry services. The narrow band systems are often quite sufficient to support these services.

In 1992, TRI obtained a database of OFS links operating in the St. Louis metropolitan area from Comsearch, Inc. The database summarizes the license information for each OFS link, including data such as the link operator, latitude and longitude of each link's transmit/receive sites, and the corresponding OFS channels for these sites. The Comsearch database indicates that 50 microwave links are in operating within a 75 mile radius of the St. Louis metropolitan area. The majority of the links support two-way operation with the standard 50 MHz frequency offset. Two of the links are operated in receive-only mode.

The Comsearch database indicates that spectrum usage is unevenly distributed throughout the St. Louis area. Twelve microwave channels are licensed to 2 or more links and twelve channels do not have a single licensed operator. Unfortunately, the 12 unallocated channel pairs do not form any contiguous spectrum blocks; vacant channels are typically situated in-between two occupied channels. Multiple licensing may be due to multi-hop links spanning across the 75 mile area or due to equipment manufacturing standards. The majority of these have transmit/receive sites located more than ten miles from the testbed, and only three links have sites within 6 miles of the testbed.

The spectrum measurements indicated moderate OFS microwave activity around the testbed. As can be seen by the sample measurement traces provided in Figure 2.2.1.4.1 and 2.2.1.4.2, microwave signals were measured throughout the 2.1 to 2.2 GHz band. The measured trace shown is representative of other traces collected around the testbed area. Referring to the figures, the strong signals near 2120 MHz and 2170 MHz correspond to links in the common carrier OFS band which is adjacent to the private OFS band. The signal near 2200 MHz is a private OFS link operating near the testbed. Based on the measured signal levels, the frequency pair for the 2200 private link should not be used. Additionally, frequencies at the low and high ends of the private OFS band should be used cautiously, as a adjacent channel interference into common carrier services is possible.

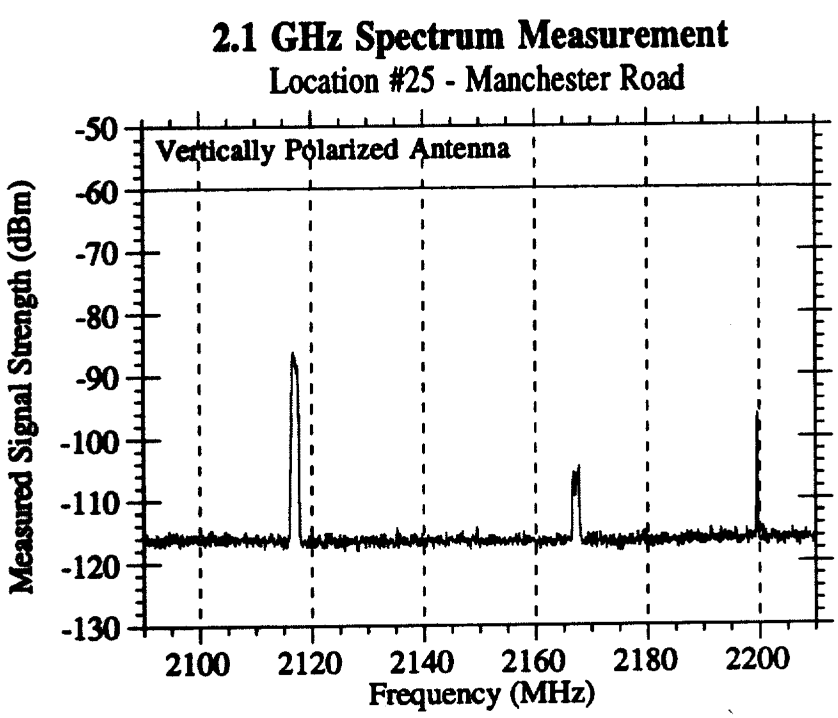

Figure 2.2.1.4.1 - Spectrum trace measured in the testbed area.

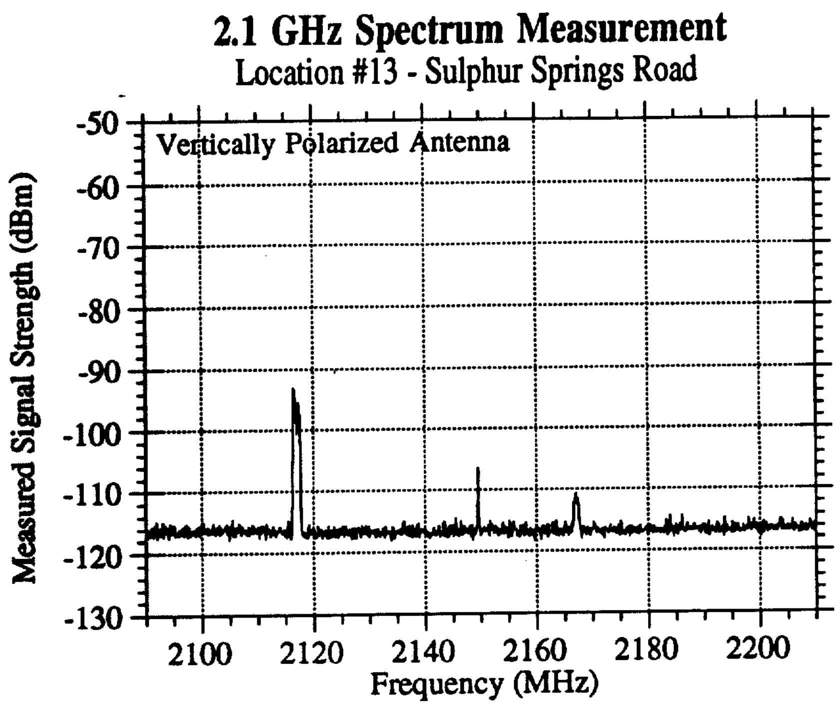

Figure 2.2.1.4.2 - Spectrum trace measured in the testbed area.

A single CW tone with an EIRP less than 1 Watt will be used for the propagation test. Any vacant microwave channel with good adjacent channel isolation (i.e., adjacent channels are used by microwave links located relatively far from the testbed area) were considered suitable for testing. These frequencies include the 2147 MHz and 2197 MHz frequency pair. However, the first frequency of this pair, 2147 MHz, will be used for the testing as it will most closely represent median performance over the entire 2.1 GHz band. Measured results indicated that 2147 MHz was available for use at all of the sites characterized.

Selection of test frequencies for testbed deployment requires a closer examination of the data. Deployment of the system requires a minimum of 5.4 MHz corresponding to 0.6 MHz for each of the nine coverage areas. While the total spectrum need not be available in one contiguous block, it would be desirable to locate at least one large block so that intrasystem adjacent channel interference could be tested using the wireless access equipment. For nine coverage areas, the aggregated power level of both the radio ports and the fixed access units will exceed 100 Watts. A radiated power level of this magnitude must be carefully considered. The radio ports and fixed access units will be transmitting in an uncoordinated fashion throughout the day. Thus long term interference effects and microwave link fading must be considered. TRI is considering these issues in a detailed spectrum sharing analysis for system deployment. A report will be issued after the detailed analysis is complete.

In 1994, we will perform detailed propagation analyses in the testbed area to more fully understand the radio environment and to develop radio port deployment guidelines for use by craft personnel.

2.3 Prototype Hardware Testing

Engineering prototype hardware was delivered to SBTR in September. This equipment consists of one Radio Port (RP) and three Wireless Fixed Access Units (WFAUs). The WFAUs are transceivers intended to be fixed to the customer's home and interface with standard indoor telephone wiring. The functionality normally required from the Radio Port Control Unit (RPCU) is integrated into the RP at this stage. In addition, analysis software was provided that allows us to determine the performance of the equipment. Data such as Word Error Rate (WER), percentage of the time each of the two diversity antennas was used, signal strength, etc., is recorded every 250 msec during a call. The RP is of reduced functionality relative to the equipment to be deployed. It can only handle two simultaneous conversations instead of seven, the WFAUs are assigned specific time slots instead of being dynamically assigned, and the receivers in all the equipment are not as sensitive as the testbed or commercial equipment will be. However, the basic functionality is supported and they can be used to characterize the system design and begin to estimate the performance of the final design.

We have conducted basic functionality tests, audio tests, and limited range testing with this equipment. We have initiated and terminated calls with the WFAUs, and made calls from one WFAU to the other, and carried on two simultaneous independent conversations. There have been no problems with this level of functionality. There are a few equipment problems in terms of support for a POTS service, but despite these problems, the system operates well and the voice quality is quite good.

The frequency response of the radio system was tested and compared to a standard 2500 desk set. We compared the audio frequency response, and the TOLR (Transmit Objective Loudness Rating), ROLR (Receive Objective Loudness Rating), and SOLR (Sidetone Objective Loudness Rating) in the laboratory environment.

We have conducted limited outdoor range testing by placing the RP in a window on the third floor of 550 Maryville Centre Drive and carrying the WFAU outside along the roadway. Other than the measurement made behind foliage, these were line-of-sight paths. We were able to initiate and maintain calls at a range of approximately 900 feet, although the link was somewhat fragile (easily lost), and a reliable link could be established at a range of about 700 feet. It was interesting, however, that within about 100-200 feet of the RP, when the WFAU passed behind a thin stand of trees, the link was lost entirely. This illustrates the sensitivity of radio propagation to foliage at these frequencies, and requires further investigation. This performance is not entirely indicative of the performance to be expected of either the commercial equipment or the equipment to be deployed in the testbed. The receiver sensitivity is 6-8 dB below that which the testbed equipment will exhibit. In addition, the RP was placed in a window inside the building. These windows have a coating to reduce heating by the sun, and as a result, we believe (from other testing that has been done in and around the building) that the window accounted for about 10 dB of propagation loss. Further range testing will be conducted with both the engineering prototypes we currently have, and with the testbed equipment when it is received.

We have also conducted limited indoor testing. The one RP was able to cover most of a single floor, had significant coverage on the floor above it, and more limited coverage two floors above, as indicated in Figure 2.3.1. The radio port was operating at 200 mW with 2 dBi omni antennas (2-branch space diversity), the WFAU also used 2 dBi omni antennas and a peak power of 100 mW. Each floor is approximately 200 feet long and 100 feet wide.

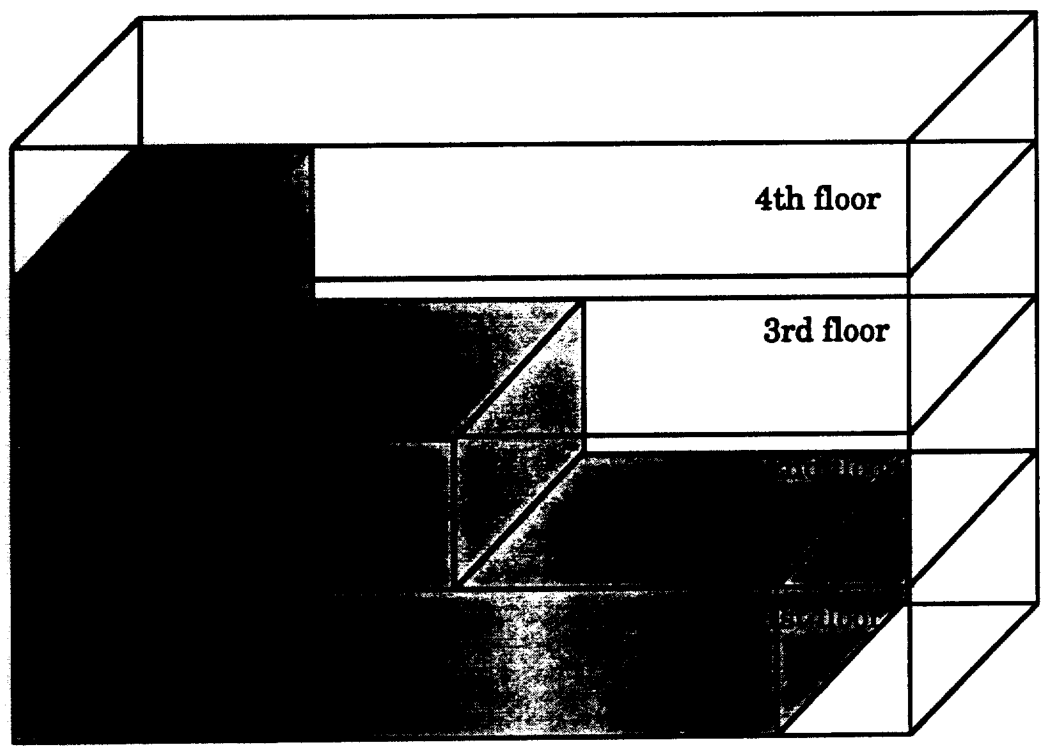

Figure 2.3.1 - Approximate indoor radio coverage of system

2.4 Future Plans

In the next quarter, we will begin finalizing the radio port locations for the wireless local loop testbed. This will entail outdoor propagation testing in the testbed area. We will set up a transmitter at each tentative radio port location and measure the signal strength at each intended WFAU location. This will allow us to determine if sufficient signal strength will be present for operation of the deployed system, and allow us to fine tune the locations if necessary. Once this is accomplished, the telephone company facilities required to provide service to the radio ports may be defined and detailed deployment plans will be drafted.

Once the radio port locations have been identified, we intend to conduct a detailed propagation analysis of the testbed area in the 2.1 to 2.2 GHz range. This will be under light foliage conditions. These measurements will be repeated in the spring or summer to quantify foliage impacts.

3.0 Progress Relating to In-Building Wireless Communications

This quarter we will report on a comparison of distributed and point source antenna systems in the in-building environment.

3.1 Experiment Objectives

In today's global economy, it is imperative that American businesses strive to maximize the productivity of each and every employee. Many of these businesses have discovered that wireless business communications systems are vital tools for remaining competitive[6]. In the hands of employees functioning in roles as diverse as the chief executive officer, shop floor managers, maintenance staff, nurses, doctors, fork lift operators -- to name just a few -- wireless telecommunications provide the means to respond to a customer's needs anyplace, anytime, and at an affordable cost. As a result, increasing numbers of businesses are augmenting existing wired communications networks with cordless telephones, wireless PBXs, alphanumeric pagers, and wireless LANs.

Southwestern Bell has been an industry leader at enabling businesses to serve customers better because of greater accessibility using wireless technologies. In March of 1993, Southwestern Bell introduced a new cellular-based Personal Communications System known as FreedomLink™. FreedomLink provides ubiquitous voice communications via the combination

[6] M. Scott, "PBX Wireless PCS", *Proc. International Communications Association Conference and Exhibition*, pp. 3 - 9, May 1993.

of Southwestern Bell's cellular network for coverage outside of the office and a wireless PBX adjunct providing coverage inside the office[7].

The in-building wireless communications channel exhibits various unique impairments that pose a tough challenge in providing optimum quality service. These impairments include: multipath fading, signal coverage, and multipath delay spread[8]. SBTR is investigating the role that distributed antenna systems, such as leaky coaxial cables, may play in mitigating such impairments.

Today, many wireless business communications systems are deployed in a *cellular-like* geometry where a radio transceiver with an integrated point source antenna provides coverage to some portion of a building floor. Multiple transceivers are deployed to fully cover the floor of a large building. While this design provides adequate coverage and simplifies installation requirements, performance improvements may be possible. In general, channel impairments characteristic of the in-building wireless communications channel are closely coupled to the physical separation between the radio transceiver and portables[9]. As this distance increases, the mean propagation path loss and multipath delay spread also increase. A distributed antenna system has the principal advantage over conventional point source antenna systems in that the portables are usually in closer proximity to the antenna system. This reduction in propagation path distance may offer several advantages including:

- **reduction in path loss variation** - receiver dynamic range requirements can be reduced significantly.
- **lower maximum delay spreads** - channel equalization may not be necessary, even for high bit rates.
- **containment of signals within the building** - spectrum utilization (frequency reuse) may be increased through a reduction in out-of-building emissions.
- **improved spectrum efficiency** - by trunking among a larger group of channels combined into a single distributed antenna system, higher trunking efficiencies may be realized. This can reduce the total number of radio channels required to serve a population of users in certain cases.

Potential disadvantages of distributed antennas include increased system costs and installation requirements over conventional point source systems.

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[7] C.F. Mason, "Wireless Fever Rises as SW Bell Unveils Commercial PCS," *Telephony*, p. 6, April 5, 1993.

[8] H. Hashemi, "The Indoor Radio Propagation Channel," *Proceedings of the IEEE*, p. 943 - 967, July 1993.

[9] T. S. Rappaport, "Characterization of UHF Multipath Radio Channels in Factory Buildings," *IEEE Transactions on Antennas and Propagation*, pp. 1058 - 1069, August 1989.

To validate and quantify the benefits of distributed antenna systems, SBTR has begun a series of multi-frequency propagation measurements. Initially, narrow band signal strength measurements are being performed using both a distributed antenna system and a conventional point source antenna system deployment. The objective is to compare the path loss characteristics of both systems to determine if the expected benefits of a distributed antenna system can be realized at an acceptable cost.

3.2 Experiment Description

Performance of the distributed antenna system will be compared with a configuration of up to three different point source antennas based on path loss measurements at various locations throughout the SBTR building. The two antenna systems will be deployed on the third floor of the building as illustrated in Figure 3.2.1.

The SBTR building is a modern office building with both hard partitioned (drywall-covered, metallic stud frame walls extending from the floor to the ceiling) and soft partitioned areas (6-foot metallic frame cubicle partitions). The building is 240 feet long by 100 feet wide and four stories high. Exterior walls consist primarily of large tinted glass windows.

Two frequency bands, 890 MHz (Cellular) and 2.4 GHz (ISM/Part 15), are selected to characterize the performance of the distributed antenna system. The selection is based on current, or anticipated, availability of in-building wireless systems operating in these bands. Specifically, three B-band cellular channel frequencies, 891.54 MHz, 892.17 MHz, and 892.80 MHz, and four frequencies in the 2.4 GHz ISM band, 2.4700 GHz, 2.4701 GHz, 2.4702 GHz, and 2.4703 GHz are being used for the measurements. Use of the cellular band frequencies was prior coordinated with the cellular operator to prevent harmful interference.

A commercially available radiating coaxial cable (sometimes referred to as a "leaky feeder") is being used as the distributed signal source. Periodically spaced slots are milled through the cable's outer conductor to permit the wave propagating within the cable to "leak" through and radiate alongside its entire length. Assuming reciprocity, external fields incident to the cable couple onto the conductors. For the measurements, the cable is installed above a suspended ceiling. The cable runs lengthwise along the building centerline and is fed at approximately 1/3 of its length from the south end. Both an 890 MHz and a 2.4 GHz unmodulated signal are fed simultaneously into the cable for the measurements. The injected power levels are 0 dBm for the 890 MHz signal and +10 dBm for the 2.4 GHz signal.

For performance comparisons, point source antenna measurements are being made in conjunction with the distributed antenna measurements. Two 890 MHz sources and three 2.4 GHz sources are positioned at appropriate locations on the building floor. The antenna locations are selected to simulate a typical system deployment where some "coverage objective" would need to be met. This will permit comparison on a system basis, where service availability and performance objectives can be measured. Each source consists of a vertically polarized omnidirectional antenna and a synthesized signal source. A 0 dBm injected power level was used for each source.

A customized measurement system is used to collect the narrow band signal strength data. The system is based around a sensitive measurement receiver and customized RF front end, which permits measurements up to 3 GHz. The receiver has a minimum detectable signal level of -100 dBm and a dynamic range of more than 60 dB. The receiver and front end are mounted on a cart outfitted with a device to measure straight-line cart displacement. The receiver and displacement measurement device are under control of an IBM compatible computer. During a measurement session, the computer continuously records the signal strength as a function of cart displacement. Vertically polarized omnidirectional antennas are used for both the 890 MHz and 2.4 GHz measurements.

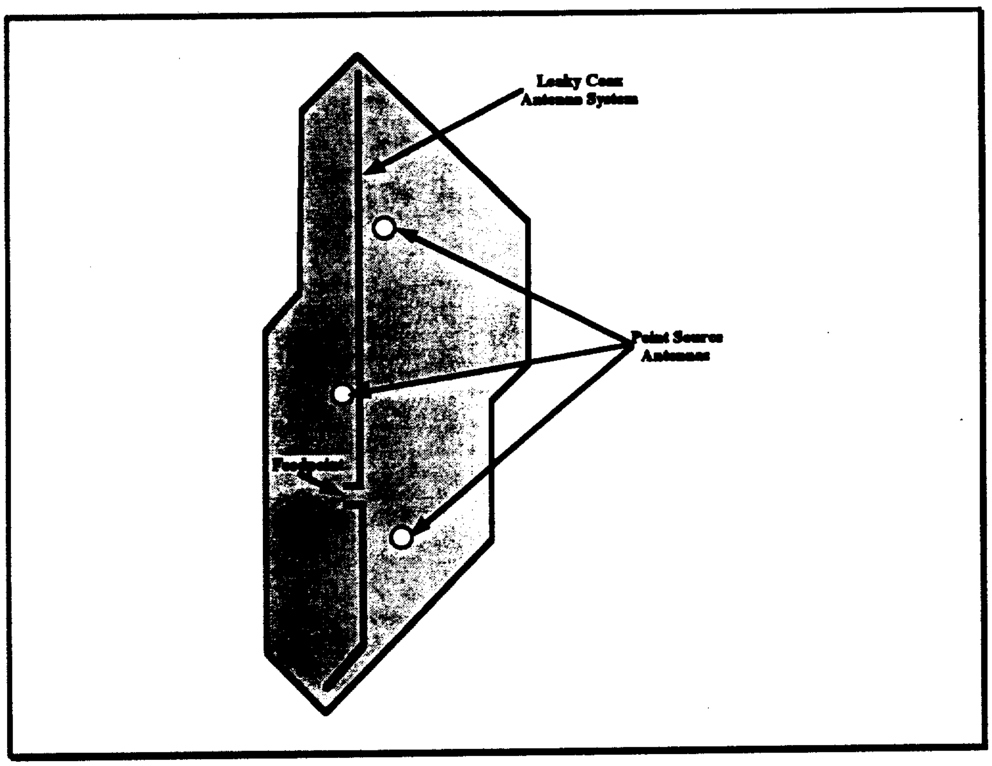

Figure 3.2.1 - SBTR Floor 3 - Leaky Coax and Point Source Antenna Deployment

3.3 Experiment Status

Our experiments commenced by scanning the two bands of interest to characterize the effects of equipment generated noise and other interference sources on our capabilities to measure low signal strengths. Because of coordination with our local cellular operations, we are able to ensure that measurements at the SBTR facility are free from interference and intermodulation products that potentially could corrupt our measurements in this band. The 2.4 GHz ISM band, on the other hand, was observed to be quite noisy. Several microwave ovens are installed in the building and are used sporadically throughout normal business hours. These were determined to be the sources of the noise observed. Figure 3.3.1 shows results of spectrum analyzer scans in the 2.4 GHz band near a typical microwave oven. Because we cannot restrict microwave oven use by other tenants of the building, we conducted our measurements during hours when the building is not normally occupied.

The second phase of our experiments consisted of measuring received signal strength samples throughout the third floor of the SBTR building. The measurement cart and antenna deployment method described in the previous section was used for this procedure. To date, more than 10 Mbytes of signal strength data has been collected using both antenna systems. Detailed experiment logs were kept so that path loss information can be calculated based on the signal strength samples measured and the equipment setup used.

Current efforts are directed toward processing the measured data to develop path loss contours as a function of frequency and signal distribution method. Figure 3.3.2 shows the results of an analysis of the cellular band data measured using the distributed antenna system. These coverage contours will validate whether a distributed antenna actually reduces the path loss variation and dynamic range requirements of in-building wireless systems. Equipment requirements for the two types of antenna systems will also be compared based on the coverage area provided.

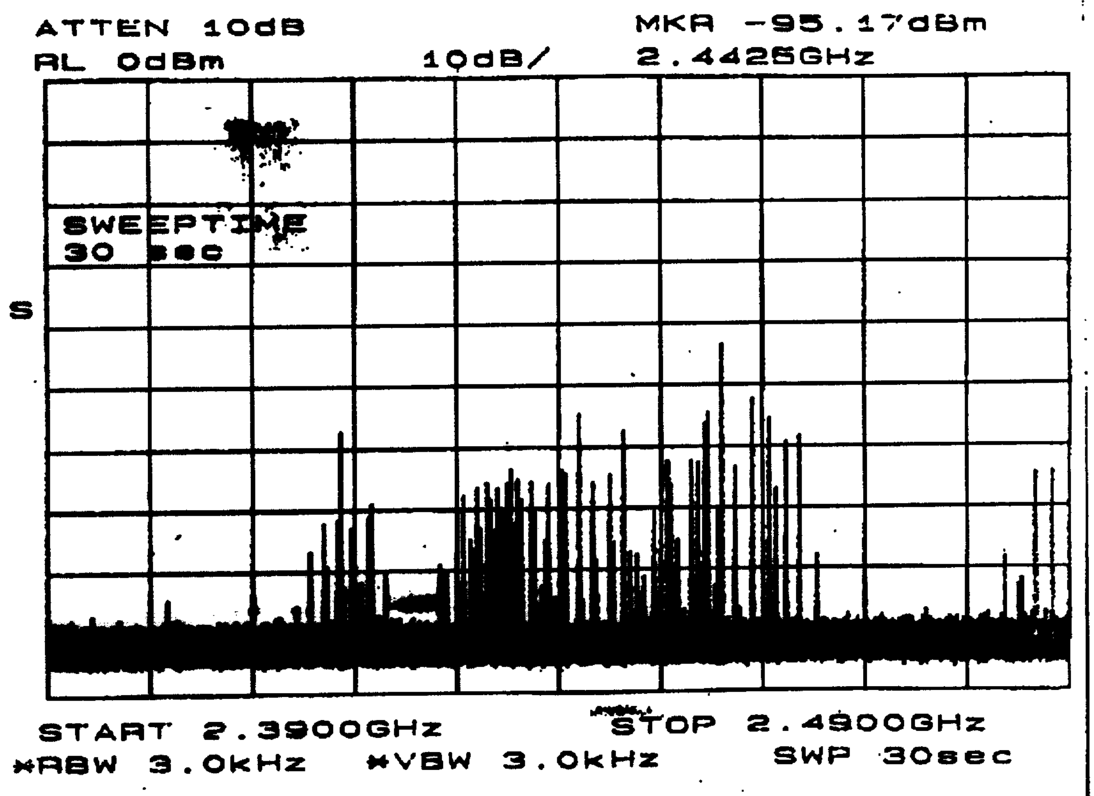

Figure 3.3.1 - Equipment Generated Noise at 2.4 GHz

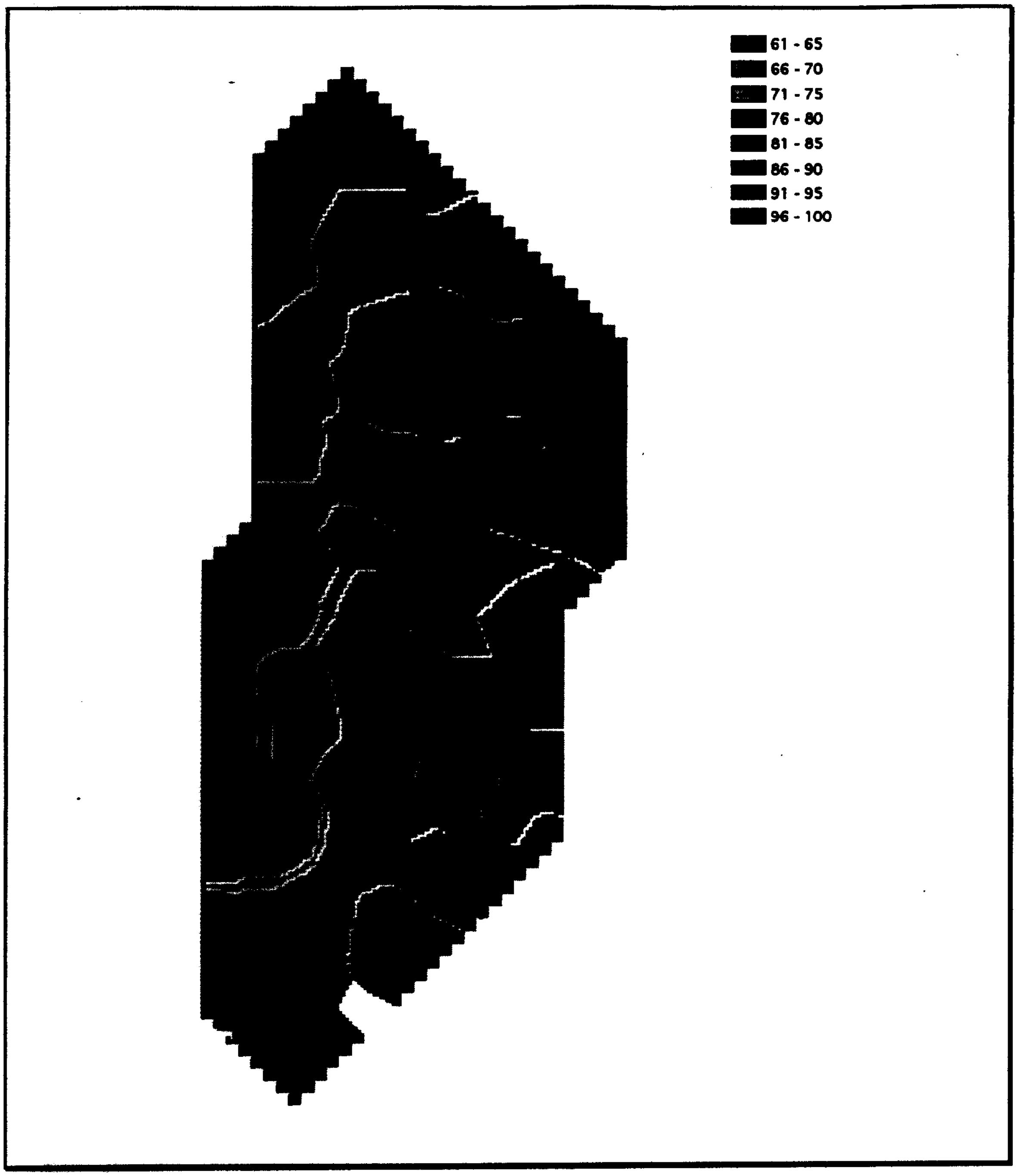

Figure 3.3.2 - SBTR Floor 3 - 850 MHz Leaky Coax Path Loss Contour Map (Path Loss Values are in dB)

3.4 Future Plans

Future activities include the completion of data processing for third floor path loss measurements. Coverage contours based on this data will then be analyzed and compared for the two types of antenna systems.

Additional measurement campaigns are planned to include:

- **building penetration measurements** - measure out-of-building signal leakage and evaluate the impact on frequency reuse.
- **floor-to-floor penetration measurements** - measure floor-to-floor signal coverage to evaluate trade-off's between coverage and frequency reuse.
- **small scale fading measurements** - measure small scale signal fading characteristics to evaluate impact of distributed antennas on fading envelope statistics and any potential improvements due to inherent "spatial diversity" of the leaky coax system.

Results of these additional experiments will reported as they become available.