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THE INSTITUTE FOR TELECOMMUNICATION SCIENCES CHANNEL SOUNDING PROGRAM

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Abstract

The Institute for Telecommunication Sciences, part of the National Telecommunications has a long-standing program to develop radio channel measurement systems. This paper briefly reviews selected examples of recent measurements, outdoor and indoor, in order to give an overview of the ITS channel sounding program. The examples presented are: 1) diversity gain versus bandwidth experiments for a 1.92 GHz mobile PCS channel in a suburban neighborhood, 2) transmission loss versus frequency (440 MHz, 1.36 GHz, and 1.92 GHz) for a mobile outdoor channel, and 3) transmission loss and RMS delay spread versus antenna type (LP or CP) in an indoor environment at 5.8 GHz. These experiments demonstrate the flexibility of the system. The important system parameters are wide bandwidths and multiple channels, as required for 3G and 4G wireless systems.

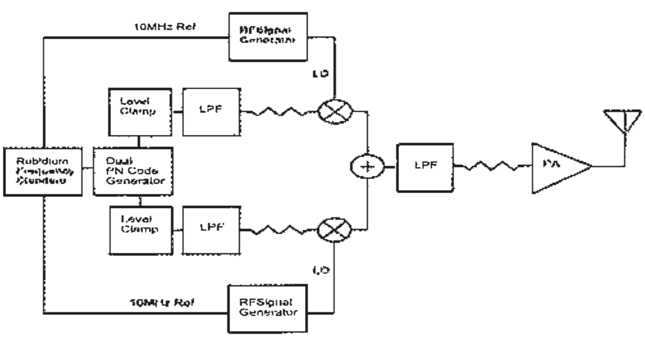
1. Introduction

The Institute for Telecommunication Sciences (ITS), part of the National Telecommunications and Information Administration (NTIA), has a long-standing program to develop radio channel measurement systems [1-10]. These channel sounding measurements have been used to investigate the effects of multipath on long distance microwave links [1-2], mobile communications [3-5,8,9], satellite links [6], and indoor channels [7,10]. Recently the emphasis has been on broadband channels suitable for high speed data communications [7-10]. Upgrades allow up to 16 channels to be measured simultaneously. This multi-channel capability makes it possible to test various diversity combining and beamforming algorithms. Broadband, multi-channel data are an important input to 3G and 4G system design. This paper will report on the current capability of the ITS channel sounding system and give examples of recent outdoor and indoor measurements.

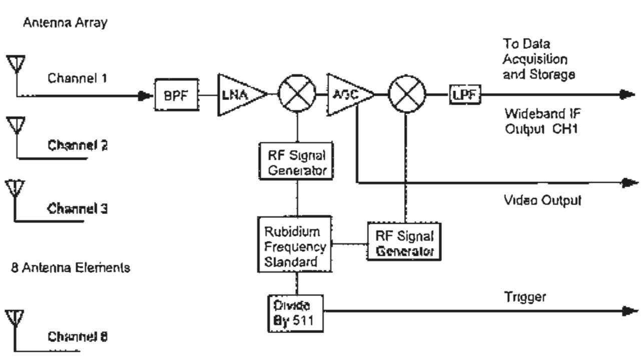
The paper is organized as follows. Section 2 briefly describes the current measurement system and outlines the configurable system parameters. Sections 3-5 give measurement examples. Section 3 reports on mobile channel measurements made at 1920 MHz (PCS band). The diversity gain for both a horizontal and vertical array using the same three antenna elements is examined. If scattering occurs primarily in the horizontal plane, then the horizontal array should yield more diversity gain than will the vertical array. However, a vertical array requires less "real estate" than does a horizontal array and may be preferable in certain cases (e.g., on a very small rooftop). Thus the data addresses the question of the tradeoffs between the two array types. In addition, the effect of bandwidth on the fading statistics is considered. Section 4 gives examples of mobile channel measurements made simultaneously at three different frequencies: 440 MHz, 1360 MHz, and 1920 MHz. The data compares the effect of frequency on basic transmission loss. Section 5 reports on indoor channel measurements made at 5.8 GHz. The use of polarization and direction diversity to achieve signal gain is considered. Section 6 concludes with a brief summary.

2. Measurement System

The ITS sounding system uses a digital channel probe (DCP). A block diagram of the system is shown in Figure 1. The DCP transmits a maximal-length pseudo-noise (PN) code. The PN code is used to biphase shift key (BPSK) modulate the radio frequency (RF) carrier. The transmitter is both frequency and bit-rate agile and can produce multiple PN codes and multiple frequencies simultaneously. This flexibility is useful for polarization and spatial diversity studies.



(a) PN transmitter - dual frequency/code



(b) multi-channel receiver

Figure 1: Block diagram for the (a) transmit and (b) receive sections.

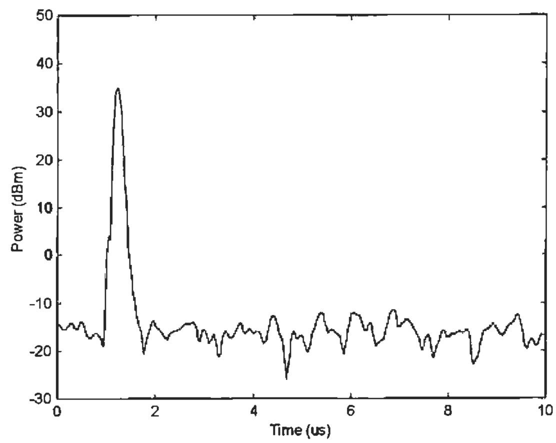
The transmitted signal, modified by the radio channel, is received, down-converted to an intermediate frequency (IF), and then digitized. A complex impulse response can be software generated by cross-correlating a copy of the transmitted PN code with the received signal after down-conversion to baseband. Additional features of the system include time of flight and Doppler measurements. System timing is maintained using rubidium oscillators at the transmitter and receiver. These clocks synchronize the PN code generators, phase lock all local oscillators, and provide sampling clocks for the digitizers. Table 1 summarizes the primary ITS channel sounding system data acquisition parameters.

Table 1. Configurable System Parameters

Parameter	ITS System
Receiver Channels	1-8 (16 w/multiplexing)
Carrier Frequency	.45 – 6 GHz
Bit Rate	.1 – 500 Mb/s
Resolution	10 μs – 2 ns
Code Type	Programmable
Code Length	Programmable
Acquisition Mode	Continuous or Burst
Positioning	GPS/Dead Reckoning
Transmitters	Multiple
Data Processing	Post or Real Time

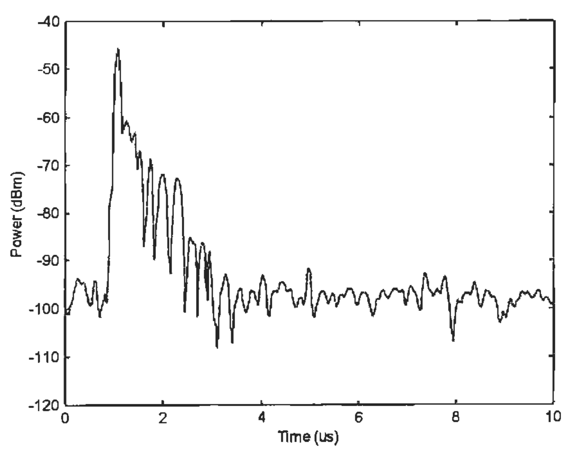
3. Horizontal versus Vertical Array Diversity Gain in a Suburban Environment

Channel sounding data were taken in a suburban neighborhood in Boulder, CO. The probe was configured to transmit a 511-bit maximal length PN code at 10 Mb/s using a 1920 MHz RF carrier. The theoretical impulse signal power to correlation noise power level ratio was 54 dB for the 511 bit PN sequence. Figure 2(a) shows a sample calibration pulse. The signal to mean noise ratio was approximately 51 dB, approaching the 54 dB theoretical value. The power spectral density (PSD) of the calibration pulse approximates a linear phase sinc function. The processing gain of the system was 27 dB when the signal power equaled the noise power. Figure 2(b) shows a sample of a received pulse showing multipath echoes. Multipath echoes separated by 100 ns could be resolved to a maximum delay of 51 μs using this configuration. After deconvolution of the system response, the channel PSD had a 12-15 MHz bandwidth with at least a 10 dB signal to noise ratio.



(a) transmitted impulse

(b)



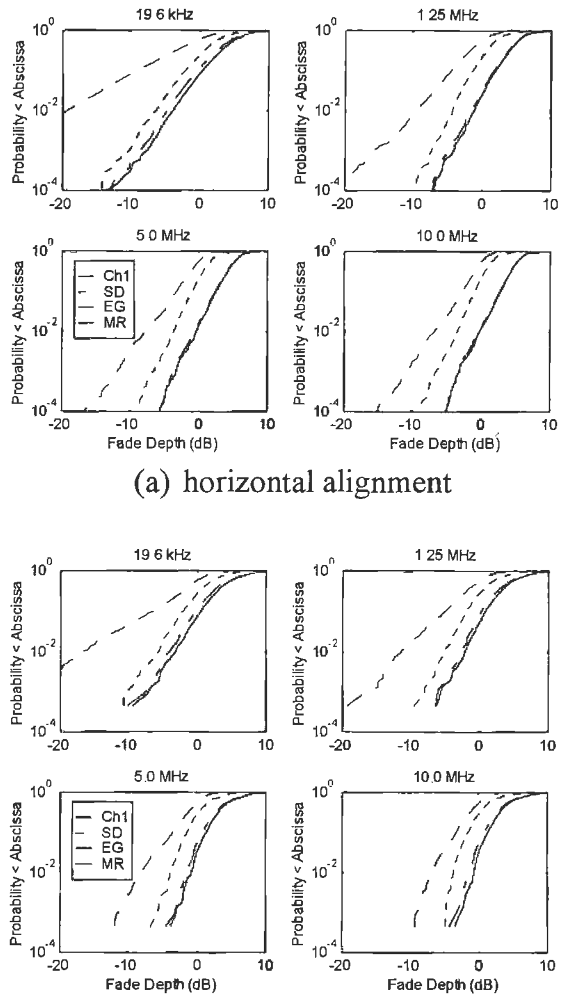
(b) received impulse with multipath

Figure 2: Sample transmitted and received impulses.

A mobile transmitting antenna and a stationary receiving array were used for the diversity gain experiment. The mobile transmitter used an omni-directional dipole antenna with 6.7 dBi of gain and a 17.5° vertical 3 dB beamwidth. The transmitting antenna was mounted at a height of 2.4 m on a van equipped with a combined GPS and dead reckoning system. The maximum transmitter power was 10 W. The two receiving arrays (horizontal and vertical) consisted of three vertically oriented PCS flat panel antennas. The elements were spaced 5λ apart (0.78 m), side by side, in the horizontal array and 8λ apart (1.25 m), one above the next center to center, in the vertical array. The vertical array spacing was limited by the height of the antenna used (1.07 m). The 3 dB azimuthal beamwidth of each antenna was 86° and the vertical 3 dB beamwidth was 8°. The nominal gain for each antenna was 14 dBi.

Fast fading is fading with respect to the local mean [11]. It is expected that fast fading should be frequency selective. Thus, signal power averaged over a broad bandwidth should be less influenced by fast fading than a narrowband signal. The total signal power in a given bandwidth was used here for the wideband fading statistics. Channels were combined using three weighting schemes: selection diversity (SD, the strongest channel is taken), equal gain combining (EG, the channels are co-phased and weighted equally), and maximal ratio combining (MR, the channels are co-pahsed and weighted according to their relative strength) [12]. Statistics are expressed in terms of the fast fading cumulative distribution functions (CDFs), i.e., the probability that the fade level (in dB) is less than a given depth with respect to the local mean. Diversity gain is typically represented as the reduction in fading at some probability level relative to single channel fading at the same probability level. The choice of channel is arbitrary as they have very similar fading statistics [10].

Figure 3 gives the CDFs for the horizontal and vertical array (>10^4 data points in each case). The three diversity combining techniques are shown for each of four different signal bandwidths (19.6 kHz, 1.25 MHz, 5.0 MHz, and 10.0 MHz). The four bandwidths were chosen to match existing and proposed CDMA standards. In each case Channel 1 (leftmost element in the horizontal array and lowest element in the vertical array) data were used as the reference level (no diversity). The diversity gain for the 90% and 99% probability levels (90% and 99% of the data are less than the values given, respectively) are summarized in Table 2. As expected, the diversity gain decreases as the bandwidth is increased. Maximal ratio combining yields the greatest diversity gain followed by equal gain combining and selection diversity, as predicted from Rayleigh fading analysis [12]. The difference in diversity gain for the three methods is primarily due to the relative increase in the average signal level. Selection diversity retains a single channel, equal gain sums three channels, while maximal ratio sums three channels with relative weights favoring the strongest channel. If fast fading for the combined signals is determined relative to the local mean of the combined signals, rather than relative to the local mean of a single channel, then all three combining techniques yield similar diversity gain results.



(a) horizontal alignment

(b) vertical alignment

Figure 3: Fade depth CDF for the three-element linear arrays.

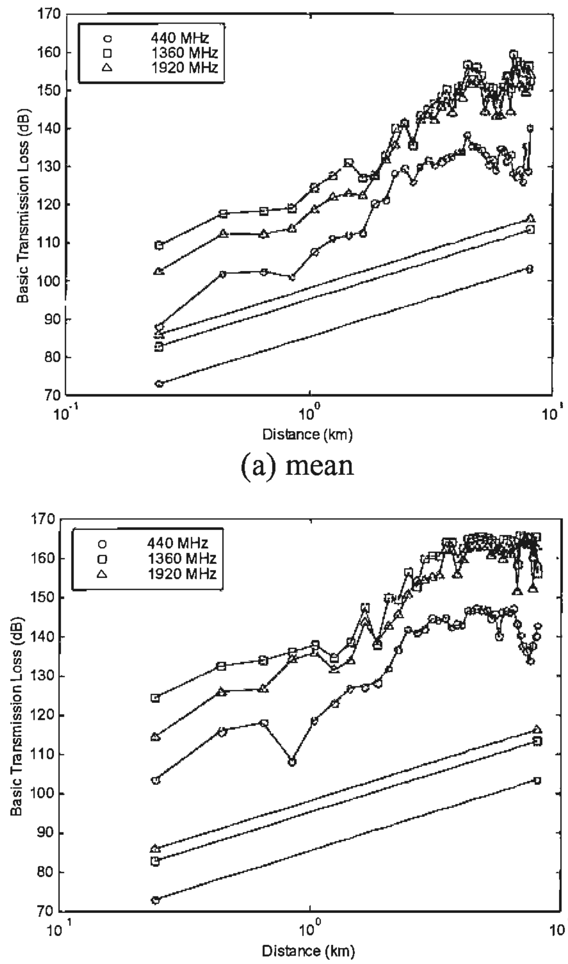
Table 2. Horizontal and Vertical Array Diversity Gain (dB)

	Signal Bandwidth											
	19.6 kHz			1.25 MHz			5.0 MHz			10.0 MHz		
Array	H	V	Δ	H	V	Δ	H	V	Δ	H	V	Δ
90%												
Selection	6.8	5.0	1.8	3.2	2.1	1.1	2.2	1.3	0.9	1.8	1.1	0.7
Equal Gain	8.5	7.0	1.5	6.2	5.1	1.1	5.6	4.6	1.0	5.4	4.4	1.0
Max Ratio	9.2	7.6	1.6	6.4	5.3	1.1	5.8	4.7	1.1	5.6	4.6	1.0
99%												
Selection	12.9	9.2	3.7	5.3	3.3	2.0	4.1	2.2	1.9	3.3	1.7	1.6
Equal Gain	14.4	11.1	3.3	8.1	6.5	1.6	7.1	5.5	1.6	6.4	4.8	1.6
Max Ratio	15.3	11.9	3.4	8.4	6.7	1.7	7.3	5.7	1.6	6.6	5.1	1.5

The above table shows that the horizontal array (H) yields more diversity gain than does the vertical array (V). This result is expected for a suburban neighborhood where scattering is primarily in the horizontal plane. The differences (Δ) between the horizontal and vertical array gains are also summarized. At the 90% fade depth probability level the horizontal array yields 1.6-1.8 dB more narrowband-case diversity gain for the various combining techniques. This increases to 3.4-3.7 dB at the 99% fade depth probability level. In each case wider bandwidths decrease the diversity gain. The decrease is to 0.8-1.0 dB and 1.5-1.6 dB for the 10 MHz data at the 90% and 99% fade depth levels, respectively. While significant, these numbers suggest that the use of vertical arrays may be justified in applications where horizontal space for an antenna array is at a premium.

4. Mobile Channel Basic Transmission Loss Measurements at 440, 1360, and 1920 MHz

In the above example multiple channels were used at the same frequency to investigate diversity gain. An alternative is to use the multiple channels at different frequencies and examine the effect of frequency on parameters such as basic transmission loss, delay statistics, and fading. An example of basic transmission loss measured simultaneously at three different frequencies, 440 MHz, 1360 MHz, and 1920 MHz, is given in Figure 4. Shown are (a) the mean measured path loss and (b) the 99% probability levels. In each case the free space transmission loss is shown as a "minimal" loss reference. The measured values increase significantly from 440 MHz to 1360 MHz. However, the 1920 MHz data is similar to the 1360 MHz data, sometimes showing less loss. This is consistent with the reduced free space path loss increase between 1360 MHz and 1920 MHz (approx. 3 dB) versus 440 MHz and 1360 MHz (approx. 10 dB). Variations in the antenna gains also contribute to frequency differences in the data. The van mounted antennas were simple monopole, or "whip antennas". Gain is usually quoted for the case of an ideal (infinite plane) ground plane. The van roof platform is a finite ground plane that has the effect of tilting the direction of maximum gain upwards. Measurements showed that this effect was more pronounced in the 1360 MHz case. Corrections for horizontal plane antenna pattern variations via GPS positions are included in the plotted data; however, vertical plane corrections via GPS elevations were not implemented here.



(a) mean

(b) 99% probability level

Figure 4: Basic transmission loss for a mobile channel at 440 MHz, 1360 MHz, and 1920 MHz. Shown are free space, and measured mean and 99% probability level values.

5. Indoor Channel Measurements at 5.8 GHz

Polarization diversity is often suggested as a method to improve indoor channel propagation. Circularly polarized signals should undergo a polarization change at highly reflecting surfaces. Thus, after a single reflection, or an odd number of reflections, the signal arrives cross polarized and is rejected by the receiving antenna. If this simple model is valid, then circular polarization diversity should yield reduced multipath interference. ITS carried out a set of measurements to examine polarization diversity gain for various indoor geometries [10]: in-room, in-corridor, corridor-corner, and corridor-to-room. Various combinations of linearly and circularly polarized antennas were considered. Measurements were made inside the U.S. Department of Commerce Radio Building in Boulder, Colorado. The Radio Building construction is primarily poured concrete columns and cinder block. Presumably, rebar exists in the exterior walls.

The basic channel sounding system setup was similar to that discussed in the previous two sections. The wideband digital sampling probe was comprised of a transmitter and a dual channel receiver. The transmitter used a 250-Mb/sec 127-bit maximal length PN code to BPSK modulate a 5.8-GHz RF carrier. The theoretical impulse signal power to correlation noise power level was 42 dB. The signal was bandpass-filtered, amplified, and fed into the transmit antenna. A step attenuator was used to control the transmit-antenna signal power in order to achieve reasonable signal-to-noise ratios for each independent measurement. The received signal, modified by the radio channel, was down-converted to an intermediate frequency and digitized at 4 samples per chip, or 1 GS/s. The chip rate of the PN code generator allowed a time delay resolution of 4 ns or 1.2 meters in a spatial sense. The maximum delay was 508 ns, which corresponds to approximately 154 m.

Nine transmit- and receive-antenna combinations were used overall [10]. Antenna calibrations were performed in an anechoic chamber to confirm manufacturer specifications and measure co- and cross-polarization gains. All directional antennas had approximately 60-degree 3-dB beamwidth. The following abbreviations are used: cavity-backed Archimedes spiral antenna (CBAS), linear-polarized log periodic antenna (LPLP), dual-linear-polarized log periodic antenna (DLPLP), and linearly-polarized omnidirectional antenna (OMNI).

Measurements were made during non-working hours so that there would be no people walking within the measurement area to influence the results. For each measurement site, the receiver was kept stationary and the transmitter, mounted on a cart, was moved back and forth along a 1.8-m (40λ) linear path at approximately 0.3 m/s. The time between impulses was 15 ms; hence, an impulse was recorded about every 0.1λ along the path. A single measurement consisted of three bursts of 128 impulse responses. The dual channel receiver was held in an equipment rack with two receiving antennas mounted on tripods 1.2 m above the ground and at 17 wavelengths separation.

Directional linearly-polarized (LP), directional circularly-polarized (CP), and omnidirectional LP antennas were employed. Results for RMS delay spread (co-polarized antennas) and basic transmission loss versus cross polarization discrimination (XPD) are shown in Figure 5. In both cases results are normalized to the OMNI-OMNI case (subscript (8)). The figure indicates strong circular depolarization and an increase in both basic transmission loss and RMS delay spread with increasing depolarization. The results also suggest less LP basic transmission loss than CP basic transmission loss for both line-of-sight and obstructed channels. Also, LP RMS delay spread is similar to CP RMS delay spread in both line-of-sight and obstructed paths. The study concludes that the apparent advantage of using LP signals over CP signals in this indoor environment may be attributed to the relatively high degree of circular depolarization measured (due to reflections and scattering). Thus, in general, the justification for using CP antennas cited above was not validated by these measurements. However, other wall types and geometries might give different results. Overall results also supported the use of omnidirectional antennas indoors to improve signal coverage. Omnidirectional measurements, however, demonstrated large delay spreads for some extraneous cases.

6. Conclusion

The ITS channel sounding system has been briefly described. The system is wideband and frequency agile, and applicable to both outdoor and indoor environments. Examples of recent applications are described. These are: 1) diversity gain versus bandwidth experiments for a mobile PCS channel in a suburban neighborhood, 2) transmission loss versus frequency for a mobile outdoor channel, and 3) transmission loss and RMS delay spread versus antenna type (LP or CP) in an indoor environment at 5.8 GHz. These experiments demonstrate the flexibility of the system. This type of data is an important input to 3G and 4G system design.

7. References

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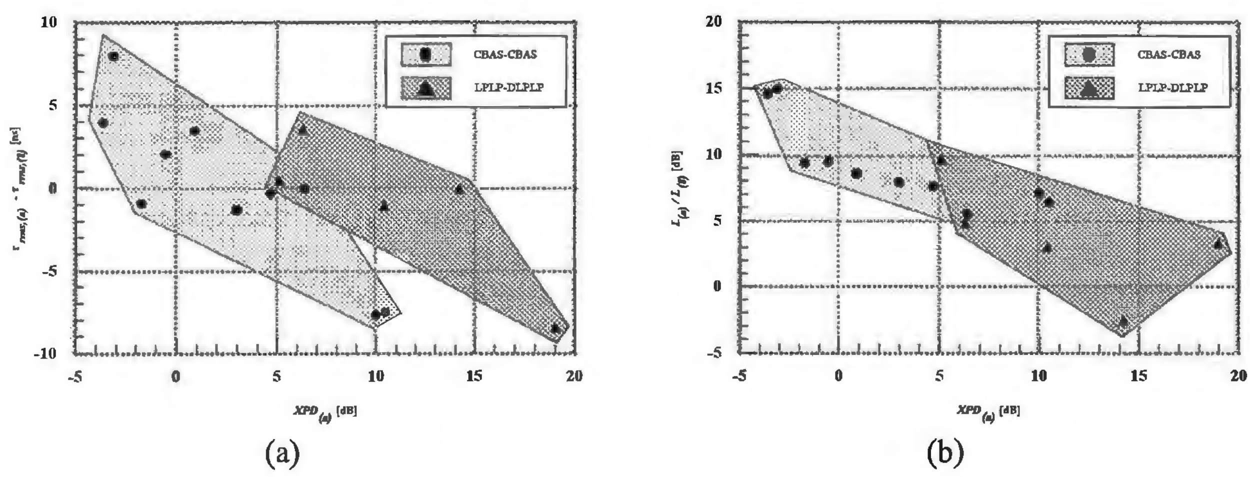

Figure 5: Co-polar (a) RMS delay spread and (b) transmission loss versus cross polarization discrimination at five indoor sites. Data were normalized to OMNI-OMNI results at each site.

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