Effects of Antenna Height, Antenna Gain, and Pattern Downtilting for Cellular Mobile Radio

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***Abstract*— Results of wideband path loss and delay spread measurements using high gain, high and low antenna heights with pattern tilting are presented. The measurements were done in the frequency range 905–915 MHz, at two existing cellular mobile radio (CMR) sites. Also presented are potential approaches for analyzing data from high gain antennas. It is shown that, to a large extent, existing models can be used to predict path loss for high gain antennas with downtilting. The results further support the notion that high sites together with high gain antennas and suitably selected pattern tilting can result in a significant reduction in path loss and delay spread, as well as reduction in power transmitted from the cell site and reduction in system interference.**

I. Introduction

THE cellular mobile radio (CMR) channel has been empirically and theoretically investigated for different environments, Parsons [1] and Lee [2]. However, little work seem to be reported on the combined effects of antenna height, high gain antenna and pattern tilting. Blackard *et al.* [3] used omnidirectional antennas and reported reduction in path loss as well as significant increase in delay spread with antenna height. Kozono [4] reported work on low antennas with tall buildings on either side. de Weck *et al.* [5] and Mohr [6] studied delay spread in mountainous terrain using different antenna heights and antenna patterns. Although both concluded that high gain antennas will have to be used with appropriate downtilting in order to avoid potential reflectors they, however, did not include downtilting in their studies. Recently, Feuerstein *et al.* [7], investigated the effects of low antenna heights (13.3 m maximum) without downtilting.

This paper investigates individual as well as combined effects of antenna height, high gain antennas and antenna downtilting for microcellular applications. When the cell site uses a high gain antenna, downtilting can direct the nulls in the antenna pattern toward the horizon to prevent energy from propagating into other cells. In a low site there is a small difference between the horizon and the edges of a cell. Discrimination between the two can increasingly improve with additional antenna height. Using a high gain, high antenna elevation and downtilting, the base station can reduce its power output relative to what would be required from a low site. Other justifications include reduced back scattering and reduced signal fluctuation throughout the coverage area.

This paper is organized as follows. Section II describes the test equipment and discusses the measurement plan. This is followed by a summary of the raw data processing techniques. Section III provides a short summary of some of the key theories and how the path loss and delay spread parameters are calculated. Section IV analyzes the data with regard to path loss and the effects of different parameters under test. Section V deals with the impact on delay spread while Section VI provides discussions and conclusions.

II. Experimental Methods

The equipment used was the Impulse Response Identification System (IRIS) assembled under the direction of AGT Research and Development [8]. At the transmitter, an Arbitrary Function Generator (AFG) generates the waveforms to be transmitted, which were maximal length sequences of lengths of 255 or 511. A Vector Signal Generator uses the output from the AFG to vector modulate a 915 MHz carrier. The bandpass filter is 20 MHz wide and the power amplifier has a 29 dB gain. The receiver front-end is an eight stage bandpass filter, identical to that of the transmitter, followed by two stages of amplification, each with a 22 dB gain and an IF filter of 200 MHz wide. The net gain through all the components of the receiver amounted to 62 dB. The baseband signal is sampled and temporarily stored on the oscilloscope which is capable of sampling up to 1 GHz sampling/second. The acquisition of the data was controlled by an IBM 486 PC which also controlled the oscilloscope adjustments. The antenna mounted on the van was a $3/4\lambda$ monopole whip antenna with an estimated gain of 4 dBi. Two different antennas were used at the base stations: a Katrien (K733 161) antenna with a 21° half power vertical beamwidth and a Sinclair (SRL410-C9-R60) antenna with a 7.1° half power vertical beamwidth. Both antennas had 60° half power horizontal beamwidths.

The experimental base station locations were chosen at existing AGT Mobility cell sites with the radio channels in the 905–915 MHz band. Two base station sites were chosen: the 90 Meter Ski Jump at Canada Olympic Park (COP) and the Blackfoot cell site, both in Calgary, Alberta. The ski jump at COP serves a suburban community in the northwest of Calgary. The highest site was atop the 90 m jump, and the lowest site was about 150 m lower at a speaker tower in the spectators' bowl. The lower site's elevation ranged between 10–100 m above the mobile locations. Twenty mobile locations were selected and the vicinity of each location was scouted out

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for the best and the worst receive capability. This was done so that the range of propagation conditions would be examined. Two locations with excellent LOS to the base station were used as reference points for comparison. The base station at the Blackfoot cell site, serving an open area, was set up on a ridge that overlooked a wide and shallow river valley. A high site was tested by using the antennas at the top of a 60 m tower whereas the low site was mounted 4 m above the ground. The mobile locations for the Blackfoot site were all along open stretches of major thoroughfares. Since the terrain was quite flat and man-made structures were sparse, most sites had good LOS to the base station. Because of the limited options given to us by the cellular service provider, only the 21° antenna was used at the COP site and the 7.1° antenna at the Blackfoot site.

The distance separation was determined by using street maps and a reasonable error was judged to be ±50 m. The elevation of the base station was taken from data supplied by the cellular operator. The elevation of the mobile was determined from city planning maps. The error in elevation separation was estimated to be ±5 m. A reasonable amount of uncertainty in downtilt angle measurement appeared to be about 0.5°.

III. Background Theory and Data Analysis

The goal of this work is to develop some understanding of the effects of high antenna heights, high gain antenna and downtilting, in light of the present understanding of radio propagation and existing prediction models. Consequently, a brief overview of the relevant prediction methods are provided.

A. Path Loss Model

The majority of prediction models for CMR, for instance [9], are based on the following path loss equation:

$$PL^{-1} = P_0\left(\frac{d_0}{d}\right)^{\gamma}, \quad P_0 = \frac{G_r G_t \lambda^2}{(4\pi)^2}\left(\frac{1}{d_0}\right)^2 \qquad (1)$$

where PL is path loss, γ is the path loss exponent, and λ is the wavelength. G_r and G_t are the receiver and transmitter antenna gains, respectively, and d_0 is the shortest distance at which free space propagation ceases to dominate. These models assume that the gain of the base station antenna is uniform throughout the coverage area, which is not the case with high gain antennas. This paper will explain how a high gain antenna can be used with the path loss model that is based on (1).

B. Fresnel Zones and Huygen's Principle

When conditions approximately support free space propagation, Fresnel zones can be also used to describe propagation path loss. The wavefront can be divided into a series of concentric circles, designated as Fresnel zones [10]. The first Fresnel zone, the innermost, contains paths that exceed the direct path by less than half a wavelength, and so is a good bound on the volume required for significant wave propagation. Most of the time, models developed for suburban or open areas would be used but, on occasion, the first Fresnel zone will be used as a clear indication that a direct path dominates.

Huygen's principle, on the other hand, explains the behavior of diffraction. When a path is obstructed by an object, radio waves will bend around the object and fill in the hole [11]. The application of Huygen's principle demonstrates that by reducing the angle through which a path must diffract, the incurred losses will decrease. This will be used to explain the changes in path loss due to different antenna heights.

C. Multipath Fading and RMS Delay Spread

The channel is a combination of paths each with its own attenuation, phase distortion, and time delay, Turin *et al.* [12]. Multipath creates time dispersion which manifests itself as frequency selective fading. The performance degradation caused by selective fading is recoverable to some degree by schemes like equalizers. One measure of time dispersion is the rms delay spread parameter, Bultitude *et al.* [13] and Cox [14]. Of practical concern in a system with time dispersion is the amount of power arriving at delayed intervals. The normalized power delay profile, $P_n(t)$, can be constructed from the impulse response by

$$P_n(t) = \frac{|h(t)|^2}{\sum_{t=t_0}^{t=t} |h(t)|^2}. \qquad (2)$$

The first moment of $P_n(t)$ is the mean excess delay, τ_m

$$\tau_m = \sum_{t_0}^{t_1} t P_n(t) \qquad (3)$$

where the time axis is scaled such that t_0 is equal to zero. The square root of the second central moment of $P_n(t)$ is the rms delay spread

$$\tau_{\rm rms} = \sqrt{\sum_{t_0}^{t_1} (t-\tau_m)^2 P_n(t)}. \qquad (4)$$

Selection of the threshold below which a signal is no longer included in the summation is important. As the threshold is lowered, more multipath components at longer delays will be included thereby increasing $\tau_{\rm rms}$. Since $\tau_{\rm rms}$ is not consistent with different thresholds one must be derived in accordance with the goals of the experiment. This question has been addressed by some authors [5], [15]. We remark that it is important to have comparable transmit powers, antenna gains, and base station locations. de Weck *et al.* [5] suggests that the measurement apparatus should experience similar path losses as the system which would normally use the channel. Based on Bultitude *et al.* [13], the threshold for $\tau_{\rm rms}$ was chosen at 20 dB below the main peak in the received impulse response. This caused some of the weaker components to be neglected. Impulse responses which did not exhibit 10 dB of range between the peak and the noise threshold were not used in the analysis.

IV. Analysis of Path Loss Data

Application of the model in (1) requires knowledge of the powers. Among the numerous approaches to calculating path loss, the most suitable was that based on the peak power of the impulse response profile [5]. The greatest peak magnitude in the impulse response is compared with the peak transmitted power. The peak power from a number of successive impulse response profiles was averaged (using spatial and temporal averaging) to remove the multipath fading. For averaging, spatial separation of samples was about one wavelength while time separation was equal to the time it takes to travel one wavelength at 50 km/h.

When high gain antennas are used, the existing path loss models can no longer be used without knowledge of the gain that the antenna has on the channel. The following analysis develops a scenario whereby the gain the antenna has on the channel is estimated. This is estimated to be the gain of the antenna pattern (in both the horizontal and vertical planes) along the direct path between the mobile unit and the base station. This is referred to as the line-of-sight (LOS) gain. The path loss slope, γ, is then computed from linear regression of the data. Because the distance measurements were considered independent, linear least squares fit was determined. To complete the model in (1), the reference, d_0 was found by the intersection of the least squares fit line and the free space path loss line.

A. Estimating the LOS Gain of a High Gain Antenna

To estimate the gain, we adopt the following reasoning: The radio channel is composed of a number of discrete paths, each reinforced according to the gain of the antenna patterns determined by the direction that it impinges on the antennas. If the antenna patterns and the characteristics of each path were known, then it would be possible to determine the effect of any antenna on the particular channel. Due to the difficulty of the problem, some simplifying assumptions were made. The antenna in the mobile was a $3/4\lambda$ whip antenna which has an omni directional pattern in the horizontal plane. Assuming that all the paths arrive at the antenna close to the horizontal plane, the paths will receive the same gain. At the cell site highly directional dipole array antennas were used. Since the cell site antenna is free and clear of all nearby obstacles, it can be assumed that all the significant energy that traverses the channel between the two antennas would arrive in roughly the same direction at the base station. Even if there are a number of reflectors nearby the mobile, the paths leaving the cell site would essentially possess the same departure angle. This implies that all the paths would be subjected to the same antenna (LOS) gain at the cell site.

The above hypothesis was first tested on the Blackfoot data. Three different angles of antenna downtilt were investigated for the high site; 4°, 7°, and 10°. For each downtilt setup, 50 measurements were recorded and the received signal strengths averaged and then converted into one average path loss value. The averaged path loss values for downtilt angles before removing the LOS gains were 94.8 dB, 96.4 dB, and 107.7 dB, respectively. After removing the LOS gains they were 109.8 dB, 108.4 dB, and 108.7 dB, respectively (antenna gains were 15 dB, 12 dB, and 1 dB). The difference between the highest average path loss value and the lowest is henceforth referred to as the spreading. By removing the LOS gains, the spreading changed from 12.9 dB to 1.4 dB, which indicates the validity of the assumption that the LOS gain is equal to the gain that the antenna has on the channel. Fig. 1 shows the average path loss of 50 measurements for each individual downtilt angle, before and after removing the LOS gain. The standard deviations were approximately 2.25 dB, 6.9 dB, and 2 dB for 4°, 7°, and 10°, respectively. The larger deviation among the measurements for the 7° setup is due to the fact that only the real channel was recorded while the complex channel was recorded for 4° and 10° setups.

A similar test was performed for the Blackfoot low site with four downtilt angles, 0°, 2°, 9°, and 10°; the difference in angles here are simply due to convenience of the setup. By removing the LOS gains the spread of the average path losses was 13.5 dB. This was only a 3.3 dB reduction in spreading compared with including the LOS gains, which indicates that paths other than the direct path are dominant in the received signal. This is most likely due to structures and terrain obstructing the first Fresnel zone of the direct path.

Analysis for all the mobile sites and antenna setups for the high and low Blackfoot sites produced an average spreading value of 6.1 dB for the high site and 11.3 dB for the low site after the LOS antenna gains have been removed. This indicates that the radio channel from the high site is more likely to be dominated by the LOS path than that from the low site. Results for the high site showed that the spreading is fairly consistently reduced by removing the LOS gain. The low site, however, experienced nearly as much divergence as convergence in spreading by removing the LOS gain. Similar tests with the COP high site showed that only the areas close in to the cell site showed a marked difference between the tilt angles. This is where the LOS path was predominant in the channel. The COP low sites also exhibited large spreading after removal of the LOS gains

B. Effects of Antenna Height on Path Loss

Using the plane earth model, it has been shown that doubling the antenna height results in a 6 dB gain, Lee [2]. The plane earth model assumes the receive signal is made up of two paths; the direct and the ground-reflected. The difference in path lengths causes the two rays to add differently depending on the distance. As distance progressively increases, the summation passes through a number of peaks and nulls until the path difference is less than half a wavelength, Fig. 2, curve (a). From there on, the signal level decreases proportionally with the square of the distance. Combined with the free space attenuation, the rate of attenuation is 40 dB/decade, which is commonly upheld as the prevailing condition for CMR channels.

By increasing the antenna height, one extends the distance at which the 40 dB/decade slope begins. The net effect is that in the region where the 40 dB/decade slope exists (beyond 6 km), the lower antenna will have a greater path loss than the

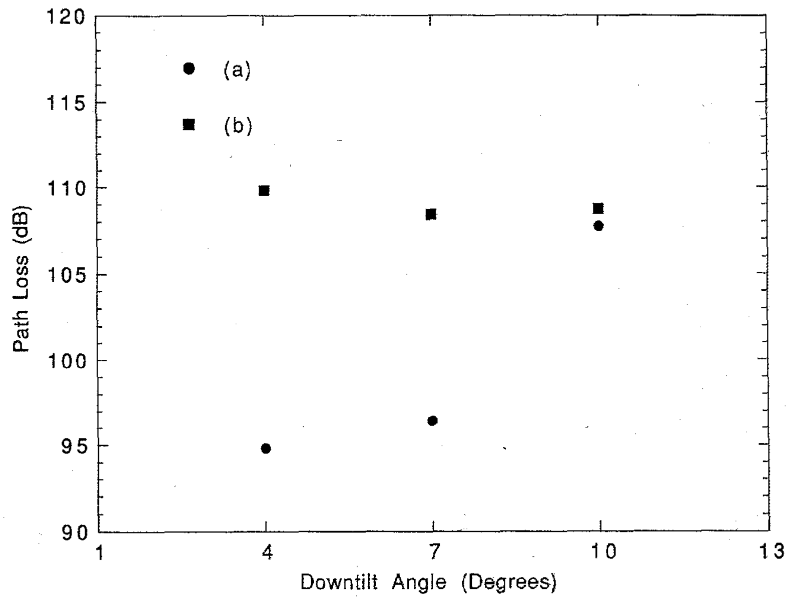


Fig. 1. Averaged path loss as a function of downtilt angle at the Blackfoot high site (a) with LOS gain and (b) without LOS gain.

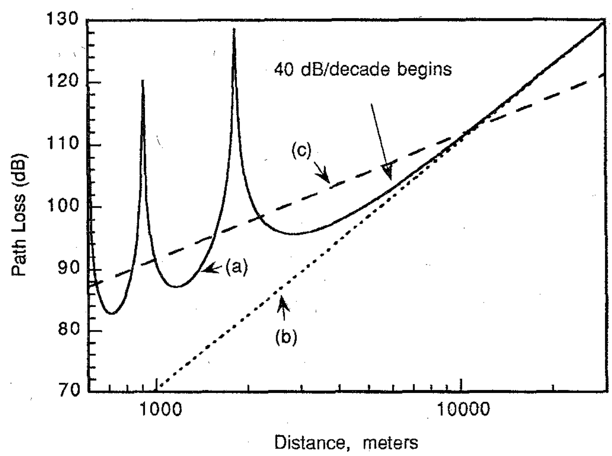


Fig. 2. Comparison of path loss (100 m cell site height and 3 m mobile antennas height) for (a) two-ray, (b) plane earth, and (c) free space.

higher antenna. Since cell radii were commonly quite large, most of the cellular coverage was located in this region and the 6 dB gain for doubling antenna height was justified. Because coverage falls below 6 km for small cells, the effect of a high antenna is no longer confined to a simple additive gain parameter. The study presented in this paper concerns the region below 6 km. To understand the effect of antenna height on cellular coverage under microcellular conditions, Lee's [9] path loss models were examined.

C. High Antenna Site

The first step in the application of Lee's method is to select an area from the area to area model, [9], which corresponds to the intended coverage region. The appropriate parameters are then extracted and transformed to match the situation in the intended coverage region. These transformations compensate for factors such as antenna gains and antenna height. The result is a path loss prediction tool of the form in (1), with P_o, d_o, and γ being defined particularly for the given situation.

The region around the Blackfoot cell site was closest to the *open area* described by Lee's model. When the parameters for the *open area* was transformed to meet the conditions at the Blackfoot cell site, Lee's model predicts the path loss to be 76 dB at the one km point with a slope of 43.5 dB/decade. However, as noted in Fig. 3, the free space path loss would be greater up until the 4.6 km point. This suggests that the free space attenuation of 20 dB/decade would prevail up until the a breakpoint at 4.6 km. Fig. 4 shows the path loss slope, using a least squares fit, for the data recorded at Blackfoot with the LOS antenna gain removed. The computed path loss of 26 dB/decade up until the 4.6 km point is 6 dB greater than the free space attenuation. Computed path loss slope beyond the 4.6 km breakpoint was around 50 dB/decade, which is about 6.5 dB greater than Lee's 43.5 dB/decade prediction. However, measured data beyond 4.6 km were not considered to be sufficient to declare this estimate accurate; the data were too close to the 4.6 km point. It must again be pointed out that the original goal was to study propagation effects below 6 km.

D. Low Antenna Site

Because the gain of the antenna could not be determined and removed from the low site data, the path loss could not be compared with existing models, in the way it was done for the high antenna site. Also, it was not known how the gain could be incorporated into the models. Consequently, the received powers were compared with those of the high antenna sites.

One potential approach that was investigated, for the Blackfoot site, was to use the effective antenna pattern (that is, the pattern that is projected onto the ground). If there is a match between, for instance, a low antenna 2° and a high

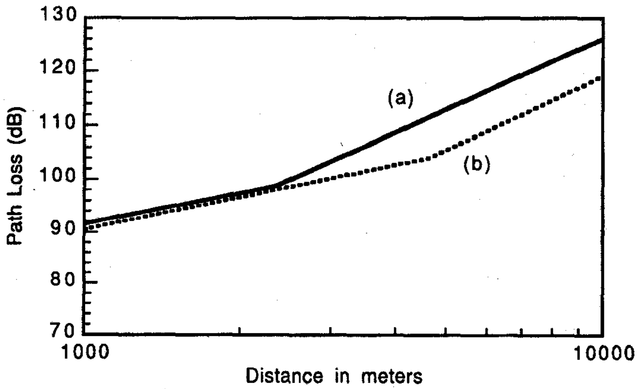


Fig. 3. Effect of antenna height according to Lee's model for open area (a) Lee's model, low site and (b) Lee's model, high site.

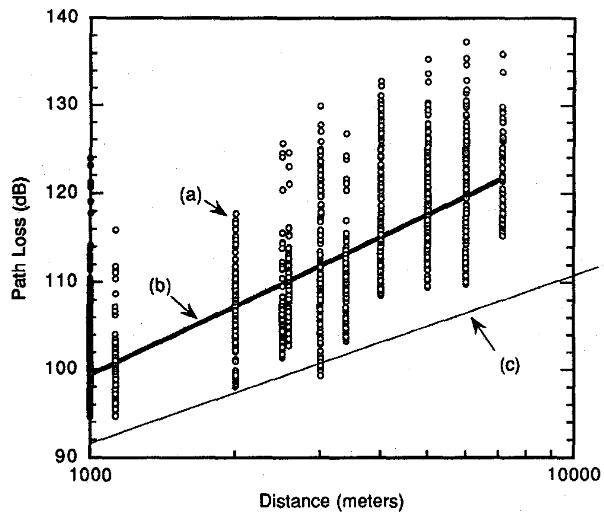


Fig. 4. Path loss as a function of propagation distance for Blackfoot high antenna site, with LOS gain removed (a) scatter plot, (b) average, 26 dB/decade, and (c) free space.

antenna 4° tilts, then the prediction methods for the high antenna could be used for the low antenna. It was discovered that the effective antenna patterns produced by the high 4° and the low 2° downtilts were very similar. It was, however, very difficulty to determine, in general, the angles that yielded similar effective patterns. Therefore, only the high 4° downtilt and the low 2° downtilt were compared. On the other hand, a direct comparison of the received powers showed a vast difference for the two downtilt angles as shown by Fig. 5, curve (a), and so this approach was not pursued further.

To gain some additional insight for the low antenna site, a comparison was made between the measured data and Lee's model prediction for the same locations for a 2° downtilt angle. Fig. 5(b) shows the power difference when *open area* was used in Lee's model prediction. As indicated by the large power difference, curve (b), this model did not accurately predict the measured path loss from the Blackfoot site. Fig. 5(c) shows the power difference when *suburban area* was used in Lee's model prediction. As indicated by the smaller power difference, curve

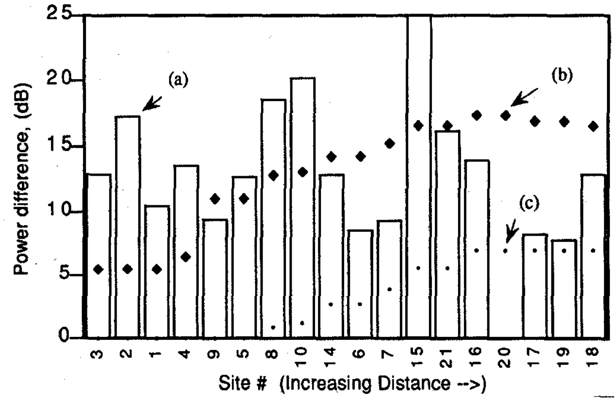


Fig. 5. Difference in received power between (a) 2° low site and 4° high site, (b) 2° low site and its Lee's prediction for open area, and (c) 2° low site and its Lee's prediction for suburban area.

(c), a better prediction was obtained by Lee's model using *suburban area* which is a harsher environment within the model's variations.

With the COP cell site located primarily in a residential community, the mobile locations were amongst many man made constructions. In comparison to the Blackfoot environment, this caused the radio channel to be more complex, with more potential scatterers and reflectors. More appropriate for these built-up areas, was found to be the theoretical model of Maciel *et al.* [17]. The model parameters allow directional antennas (in a limited sense) and antenna height, however, the tool is defined for antenna heights near the same height as the buildings. Therefore, for the COP experiment some extrapolation of the model was needed. The model divides the path loss into three components: the free space loss between the two antennas and the excess path loss which consists of diffraction loss, L_{e1}, from the last building to the mobile and the forward diffraction loss, L_{e2}, over the rows of buildings from the base station to the last building,

$$L_{e2} = -10 * \log\left(GQ^2\right) \tag{5}$$

where G is the gain of the base station antenna in the direction of the last building and Q is a dimensionless parameter that depends on the configuration and dimensions of the channel. As the base station antenna height increases in relation to the interfering building heights, Q approaches 1. Thus the excess loss is simply that imposed by the antenna pattern. This was the case at both the low and high antenna COP sites so Q was set to 1. The diffraction loss down to the mobile, L_{e1}, is only a function of the distance from the last rooftop and the angle through which the path must diffract. And so, as the angle from the rooftop to the base station increases, the angle of diffraction to the mobile would decrease which, in turn, would decrease the diffraction loss. Therefore, the model predicts that if there is a clear LOS path there would be little difference in the path loss from a high site compared with a low site. However, when the direct path is blocked by a building near to the mobile, the high site would have less path loss.

The measurements from COP were taken at locations which had a LOS position as well as a blocked LOS position. These

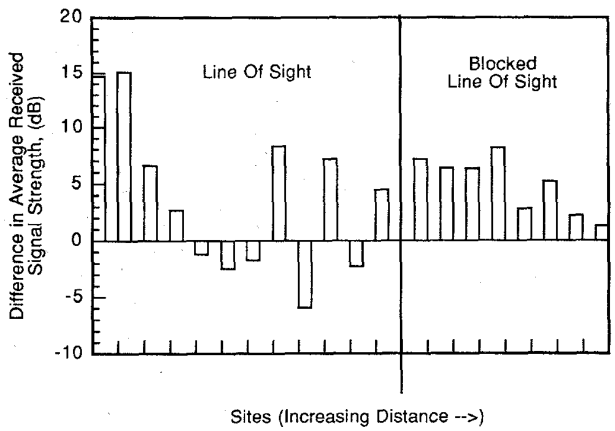


Fig. 6. Comparison of average received power from high and low COP antenna sites, LOS gains removed.

points were typically within two blocks of each other. In the LOS locations, the high site delivered a better signal in slightly more than half the cases, while in the blocked LOS locations it always provided a better signal, Fig. 6. A negative value indicates that the high site experienced more path loss than the low site. However, the improvement decreased with increasing distance which is in accordance with the theory proposed by Maciel *et al.* [17]. This is because the diffraction angle produced by the high site approaches that of the low site.

V. Analysis of Delay Spread

The time dispersion of the signal is quantitatively measured by delay spread parameters. This section discusses the effect of antenna height and downtilting on the delay spread.

A. *Effect of Antenna Height and Antenna Downtilting*

Fig. 7(a) and (b) compares rms delay spreads from high and low antenna sites. At the Blackfoot site very little delay spread was anticipated since only a few occasional reflections were expected from some of the factory buildings or an overpass. For the high site, only 1% of the rms delay spread measurements exceeded 0.40 μs while for the low site, the 1% level was 0.83 μs. The high site possessed superior rms delay spread qualities over the low site.

Data from COP site, Fig. 7(b), did not show dramatic improvement as did the Blackfoot site. The high site experienced rms delay spread of more than 2.23 μs for 1% of the time whereas the low site value was 2.93 μs. This is because the mobile traveled amongst many buildings, causing the direct path to be blocked and creating many reflections. Also, the river banks provided some short, strong reflections and the large hill on the horizon induced longer delayed paths.

Fig. 8(a) and (b) compares rms delay spreads from high antenna sites as a function of downtilt angles at both the Blackfoot and COP cell sites. The 8° downtilted antenna setups were always superior to the 1° setups. At the Blackfoot site, only for 1% of the time did the rms delay spread exceed 0.43 μs for the 8° downtilted antenna compared to 0.78 μs for the 1° downtilted antenna. At the COP site, the rms delay spread exceeded 1.97 μs for 1% of the time for the 8° downtilted antennas and 3.07 μs for the 1° antennas. These are significant improvements in delay spread reduction for both sites.

Other authors, [3], [5], [15], have reported improvements as well as degradation in the rms delay spread as a result of increasing the base station antenna height. These results were, however, generated under different conditions. For example, [3] and [15] were concerned with base station antennas near the same height as the local buildings while de Weck *et al.* [3], were concerned with high base station antenna sites and directional antennas in mountainous terrain. The prediction of de Weck *et al.* [3] and Mohr [6], that rms delay spread could be reduced by proper selection of base station heights and antenna patterns have also been supported by the experimental results of the paper.

Because of the limited options offered to us by the service provider we were unable to carry out measurements with both the 7.1° and 21° antennas at one site. Consequently, the paper does not present a comparison of delay spread results as a function of antenna gain.

VI. Discussion and Conclusion

A. *Effect on Path Loss*

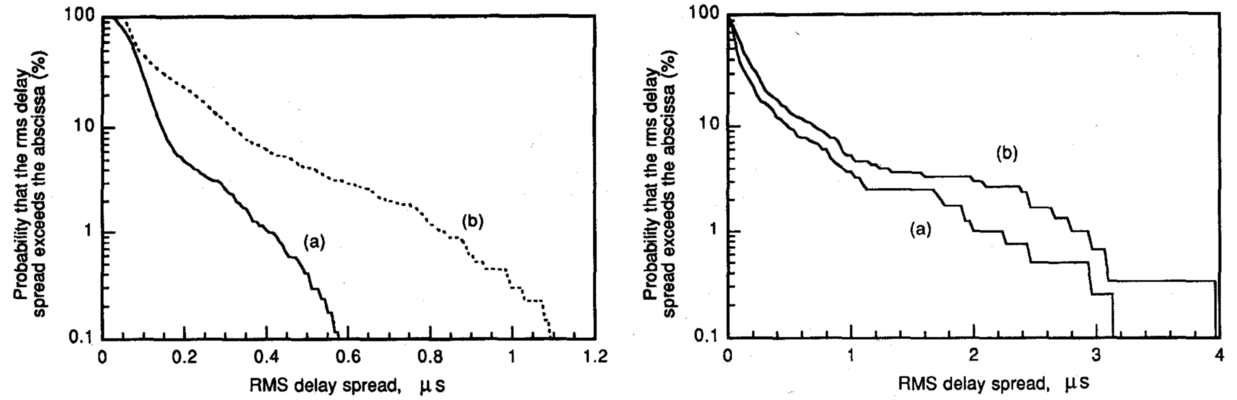
Two existing path loss models, Lee's [2] and Maciel's [17], were used to explain the relationship between height and path loss. The effects were then supported through analysis of the measured data at existing CMR cell sites, the Blackfoot and COP sites.

Lee's models produced accurate predictions for the Blackfoot high site. For the low site, the best prediction was produced when the channel environment was chosen as suburban, instead of open area, in Lee's model. This indicates that when a low antenna is used, the signal will experience a harsher environment than when a high antenna is used.

Data from the COP site was accurately predicted by Maciel's theoretical model. The proximity of the mobile antenna height to those of the buildings caused additional path loss as the direct path diffracts over an obstacle near the mobile. By raising the antenna height, the angle through which the path must diffract was reduced, thereby reducing diffraction path loss. However, this improvement became less significant as the distance between the mobile and base station increased.

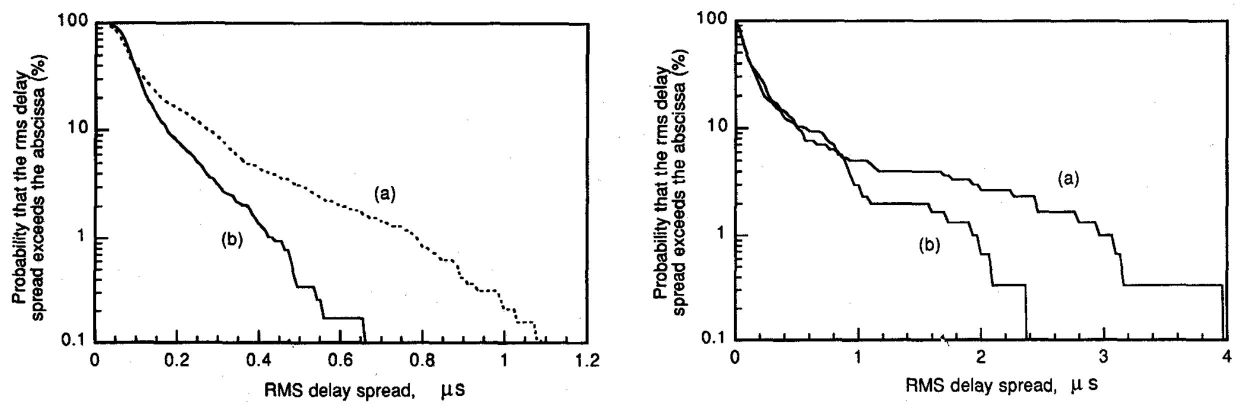
B. *Effect of Height and Downtilting on Delay Spread*

A major objective is to minimize time dispersion (delay spread) due to multipath. Several researchers [3]–[6], [15], [18] have suggested that the use of suitable antenna downtilting will result in lower delay spreads. The work reported in this paper has shown this to be viable. The experimental results reported here suggest that a high antenna site strengthens the direct path relative to the reflected paths. This would cause a higher proportion of the received energy to be concentrated in the earlier arrivals, resulting in a reduced delay spread. References [5] and [6] reported that when the antenna height is close to that of the buildings, any height increase would degrade the



(a) (b)

Fig. 7. (a) Comparison of rms delay spread for 9° downtilt at the Blackfoot cell site, (a) high antenna and (b) low antenna; 20 dB maximum threshold. (b) Comparison of rms delay spread for 8° downtilt at the COP site, (a) high antenna and (b) low antenna; maximum threshold 20 dB.



(a) (b)

Fig. 8. (a) RMS delay spread for two downtilt angles at blackfoot high antenna site, (a) 1° downtilt and (b) 8° downtilt; 20 dB maximum threshold. (b) RMS delay spread for two downtilt angles at the COP high antenna site (a) 1° downtilt and (b) 8° downtilt; 20 dB maximum threshold.

delay spread due to long distance reflectors. The conclusion made by this paper is that downtilting and high sites can not be effectively used without each other. This is because the improvement from raising the base station antenna is partly offset by long distance reflectors, if downtilting is not used. Also, downtilting is useless from a low site because the edge of the cell can not be discriminated from the horizon.

C. Impact on CMR System Design

Two major goals of a CMR system engineer are to provide adequate coverage within the cell and to ensure sufficient attenuation of the signal outside of the desired cell. By using a high antenna site, path loss within the cell was reduced. The environment perceived by the base station caused less attenuation compared with a lower site, free space attenuation persisted for a greater portion of the cell and the attenuation introduced by structures nearby the mobile was reduced. The benefit of reduced path loss is that the base station can transmit lower power and there will be less variation in the signal level throughout the cell. The high antenna with downtilting will be able to discriminate the edge of the intended coverage area and significantly reduce system interference.

D. Urban/Cluttered Environments

Measurements carried out in the urban area showed insignificant improvement in path loss. The reductions in interference and delay spread due to downtilting were in many cases greatly diminished. Capacity limits on a CMR system will therefore first occur in the urban areas.

Typically, these environments are composed of tall office towers which generate much of the cellular traffic. AGT Mobility has successfully used the principles of high antenna gains and pattern tilting to increase the system capacity and control interference at the same time. However, instead of a high site, a relatively low site (typically three stories high) was chosen just outside the downtown core. Then a high gain antenna was used with an uptilted pattern. The null of the antenna pattern (25 dB down from the main lobe) was directed horizontally. The effective coverage area only included the upper floors of the office towers. The energy that was transmitted from the high site and reflected from the office towers was directed upwards away from other cells. Lower sites, land based units with horizontal tilt patterns provided service to the lower stories. Signals from these sites were severely attenuated by the antenna pattern of the sites that provided coverage to the higher stories. This has been implemented in the Calgary system and plans are being developed for a second site.

Other considerations that have not been addressed include back scattering and delay spread versus antenna gain. These aspects are beyond the scope of experiments that this paper reports.

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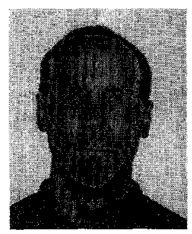

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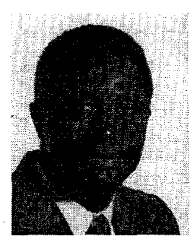

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