Radiowave Propagation Measurements for Sharing Spectrum Between Point-to-point Microwave Radios and Personal Communications Systems

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ABSTRACT

A CW radiowave propagation experiment was performed to study spectrum sharing possibilities in the New York City region. The results showed that the isolation measured between the microwave and a PCS system on the street was more dependent upon building shadowing and street orientation within the city than on the distance between the two systems for distances less than 20 km. At greater distances, the topography, including intervening hills and the curvature of the earth which could shield the systems, played a strong role in providing isolation. The system dependent isolation required for sharing could be found even in the conventional main beam direction in locations surrounded by shadowing objects. Conversely, strong signals were often found well away from the main beam. Thus, there was measurable degradation of the microwave antenna discrimination relative to its (free-space) directivity. Closer in, the isolation varied widely, with regions of strong signals popping up in the shadows. The median difference between co-polarized and cross-polarized signal levels was only 7.5 dB. Occasionally, cross-polarized signals were stronger than co-polarized signals. Statistical area models under-predicted the isolation, missing most sharable regions.

1 INTRODUCTION

Frequencies in the 1.9 GHz band have been allocated for emerging Portable Communications Systems around the world. In the United States and elsewhere, these frequencies have often been granted under the proviso that the spectrum should be shared between the PCS services and incumbent point-to-point microwave (OFS) communications systems. Permissible levels of interference into OFS systems are governed by industry practices. In the US, these are detailed in Bulletin 10-F, published by the Telecommunications Industry Association (TIA) [1].

This paper studies the reception on the ground of signals from a test point-to-point microwave antenna. This experiment was performed to provide information on spectrum sharing possibilities for Bulletin 10-F [1].

2 THE EXPERIMENT

A four-foot (1.2 m) parabolic grid antenna was used to represent one end of a point-to-point microwave link, operating in the 1850-1990 MHz band. The transmitter power was +34 dBm into the antenna port. The nominal antenna gain was 26 dBi, giving an equivalent isotropic radiated power (EIRP) of +60 dBm.

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The receiver system was in a pickup truck. The vertically polarized receiver antenna was mounted at a height of 5.8 ft (1.8 m). It had dipole-like pattern with a nominal gain of 0 dBi. The receiver bandwidth was only 1 kHz. The detected signal was continuously sampled at intervals of about 1.8 inches (4.6 cm) of travel. The vehicle was also equipped with a non-satellite based geo-location system which enabled its position to be known at all times.

The transmitter was placed, successively, at two sites in Manhattan, New York City. The first site was the Empire State Building, at 34th Street and 5th Avenue. The NYNEX radio room on the 87th floor, was used. This site was 1076 ft (328 m) above ground level. The antenna room was on the eastern face of the building, with the radome-like wall extending partially to the northern and southern faces. One end of several operational microwave links were also located in this room. The antenna was pointed "north" along 5th Avenue, at an azimuth of 29 degrees for two sets of data This is also the approximate orientation of Manhattan island, and extends into upstate New York. The transmitting antenna was vertically polarized for the first set and horizontally polarized for the second. For the third set of data, the antenna was pointed "south" at Wall Street, at an azimuth of 203 degrees. The main beam of this vertically polarized antenna crossed the bay into New Jersey. The fourth data set was obtained with the microwave antenna placed outside on a parapet, atop the NYNEX building at 210 West 18th Street. The antenna was pointed "south" at Wall Street. Any radiation from the back of the antenna was blocked by the building. The azimuth was 194 degrees and the antenna was vertically polarized.

The data consisting, usually, of contiguous records of 1000 signal samples (155 ft, 48 m in total distance), was stored with the geo-location obtained from the measurement equipment. The vehicle was driven on the avenues and streets of the city and on the highways outside, traveling within a radius of about 120 km. All the runs made with each pointing of the microwave antenna made up a set that consisted of several hundreds of miles (km) of data. Since the received data were subject to multipath fading fluctuations, the median isolation of each complete 1000 sample record was extracted. This spatial processing over about 48 m was considered to characterize the signal well over the given distance.

3 ISOLATION

3.1 Path Loss and Isolation

The generalized Friis' transmission formula between two antennas may be written, in logarithmic form, as

$$P_r = P_t + U_t(\phi) + U_r(\varphi) - L_P \quad [\text{dBm}] \qquad (3.1\text{-}1)$$

where,

- P_t = Transmitter Power in dBm
- P_r = Received Power in dBm
- $U_t(\phi)$ = Gain Function of transmitter antenna in the direction ϕ of the receiver in dBi
- $U_r(\varphi)$ = Gain Function of receiver antenna in the direction φ of the transmitter in dBi
- L_P = Path Loss between Isotropic antennas in dB

Path loss will *always* be defined between isotropic antennas and antenna gains referred to the isotrope as well, whether the qualifier is used or not. We may further write the gain function of an antenna as

$$U(\phi)\ \text{dB} = G\ \text{dB} - \Delta(\phi)\ \text{dB} \quad [\text{dB}] \qquad (3.1\text{-}2)$$

where

- G = Gain of the antenna = $U(\phi)_{max}$ is the maximum value of the gain function.
- $\Delta(\phi)$ = Discrimination function of the antenna, in the direction ϕ.

The value of the discrimination function in the direction of maximum gain is 0 dB. Hence, any antenna may be thought of as in isotropic radiator with gain, G, which is enclosed in a shell with attenuation in different directions described by the discrimination function, $\Delta(\phi)$.

Substituting for $U_t(\phi)$ and $U_r(\varphi)$ in (3.1-1) and collecting terms, we define the Isolation, L_I in dB as

$$L_I = L_P + \Delta_t(\phi) + \Delta_r(\varphi) \quad [\text{dB}] \qquad (3.1\text{-}3)$$

so that

$$P_r = P_t + G_t + G_r - L_I \quad [\text{dBm}] \qquad (3.1\text{-}4)$$

The Isolation includes the path loss and the discriminations of the two antennas in a link. The isolation equals the path loss only when isotropic antennas are used, or when antennas are aligned along their directions of maximum gain (usually along the boresight in the case of a parabolic antenna). During measurements, it allows the antenna gain, or alternatively, the Equivalent Isotropic Radiated Power (EIRP = $P_t + G_t$), to be used in the transmission formula. Since the three-dimensional angular discrimination function is usually not known, its effect is lumped into the Isolation term. We see, therefore, that during signal level measurements using antennas with gain, when the mobile receiver is at some arbitrary position relative to the microwave antenna, the only propagation loss quantity which can be measured directly is the Isolation.

3.2 Required Isolation for Spectrum Sharing

TIA Bulletin 10 requires that when a PCS link is installed at a frequency used by point-to-point microwave links, the interference generated by the PCS system should not raise the thermal noise floor of an existing microwave link by more than 1 dB. Therefore, since the desired and interfering powers are uncorrelated, the power received from the PCS system, if it is noise-like, should be at-least 6 dB below the microwave radio's noise floor [2]. The thermal noise floor of a microwave receiver with a noise bandwidth of 10 MHz and noise figure of 4 dB would be -100 dBm. Thus, the total interference permitted from a coordinating PCS system is only -106 dBm.

The isolation required between a PCS system and the microwave radio to achieve this may be calculated according to the following three examples. Consider two types of portable sets, operating in time division multiplexed systems with 8 bursts per TDMA frame. One set is vehicle based and the other is a hand portable. Their base stations, in each case, are assumed to transmit continuously at 1 watt. A microwave radio at that frequency has an antenna gain of 30 dBi. Detailed calculations are given in Table 1.

Table 1: Required co-channel Isolation Between a PCS system and a Microwave Receiver

Parameter	Base Station	Vehicular System	Hand Portables
PCS transmitter burst power when on	30 dBm	30 dBm	20 dBm
Duty factor with 8 time slots per frame	0 dB	-9 dB	-9 dB
PCS antenna gain	10 dB	3 dB	0 dB
Microwave receiver antenna gain	30 dB	30 dB	30 dB
Maximum Interference power, P_int_max	-106 dBm	-106 dBm	-106 dBm
Hence minimum required Isolation for a single unit to share spectrum (A)	176 dB	160 dB	147 dB
Minimum required Isolation for 100 units to share spectrum (B)	196 dB	180 dB	167 dB
Minimum required Isolation for 1000 units to share spectrum (C)	206 dB	190 dB	177 dB

Note that this table does not imply that all three classes of emitter are co-existing with the same microwave radio simultaneously. Each class is being evaluated by itself. It does show that higher power PCS systems require more isolation to avoid violating the TIA sharing criterion. Also, more users could be supported if some of them have greater isolation than the minimum numbers given above. Conversely, if a single unit were to move to a position with less isolation than the numbers given above in rows B or C, a large number of users would have to increase their isolation significantly to maintain the same total number of users. Even this can only continue as long as the user with the lowest isolation does not reach the single user value, (A), given in Table 1. It should be also noted that the TDMA duty factor correction is strictly applicable only for PCS interferers spread uniformly over all time slots.

4 MEASURED DATA

In this section, we show examples of measured data. To provide perspective to the data, we relate the measured isolation to the system examples given in section 3.2. The isolation levels given in the examples were selected to fall within the range of measured data. They are for illustrative purposes only and do not imply that PCS systems can be economically deployed for the corresponding numbers of users given in Table 1. The reader must repeat the calculations of isolation levels that correspond to the appropriate number of users for actual PCS systems.

4.1 Measured Isolation

Figure 1 shows a scatter plot of Isolation (dB) vs. T-R separation (km) for co-polarized measurement locations with the transmitter on the Empire State Building (328 m high) with an azimuth of 203 degrees. Each data point represents the median value over a distance of about 155 feet. Note the large variability of isolation for a fixed T-R separation. The figure indicate several locations at distances less that 20 km where there is sufficient isolation for a small number of PCS emitters, as described in the previous example, to share the spectrum. However, in order to guarantee that there are no locations within a given distance that do not have sufficient isolation, a PCS radiator must be located over the horizon (>80 km) from a sensitive microwave receiver.

Figure 1 also shows an overlay of several propagation models. The Hata propagation model with a US correction factor of -12 dB, the Longley-Rice Area model for 50 % of the users, and the free space path loss are shown for an antenna located 328 m above the ground. The values predicted by these curves are path loss, while the measured data represents isolation. The free space radiation pattern of the transmitting antenna at ground level is not known. Hence, it is difficult to accurately compute the path loss from the measured isolation data in off-boresight directions. The measured data generally shows much higher isolation than the path loss models predict. At long distances, when the earth bulge intrudes, the separation between the transmitter and receiver causes a significant increase in isolation. In general, the models do not appear to fit the data very well. In fact, the Longley-Rice Area model (50%) appears to be a good bound of *minimum* isolation at a given distance.

Next, as an example, consider the low power system described in the third column of Table 1. Figure 2 shows a plot of all measurement locations when the Empire State Building transmitter was pointed at an azimuth of 29 degrees with vertical polarization. Figure 2a shows the locations where the isolation is greater than 180 dB, and Figure 2b shows the locations where the isolation is less than 180 dB. The transmitter is located at (0,0) and the solid lines represent a five degree beam along the antenna boresight. Each "dot" on the graph is the median isolation computed over 155 ft or 48 m (1000 points).

The region shown includes parts of southern New York State, Westchester, and Connecticut to the north, the I-95 highway along the coast to the northeast, Long-Island, to the east, and parts of New Jersey to the west and south, with Sandy Hook bay in-between. The beam passes over Westchester, which has moderately hilly terrain, covered with vegetation. Hence, it is seen from Figure 2a that isolation near 180 dB exists even on the highway very close the beam. However, there are a significant number of off-boresight locations, even over 30 km away, which do not have this isolation. These are interspersed among the locations which exceed this isolation. Conversely, close in at Long Island, there are regions with enough isolation in the midst of high signal strength areas.

Figure 3 shows the cumulative distribution of the isolation for all locations less than 20 km from the transmitter. The four curves in Figure 3 represent measured data from the different data sets. Consider a critical threshold of 180 dB isolation for a high power vehicular PCS system in the example given in Table 1, column 2. If each user is at 180 dB isolation, at most 100 users in the whole area can share the spectrum. Figure 3 shows that users located less than 20 km from the microwave receiver have 180 dB or greater isolation at 10-25 percent of the locations.

4.2 Polarization Discrimination

Measurements were made with the Empire State Building transmitter at 29 degrees Azimuth with both vertical and horizontal transmitter polarizations. The receiver antenna remained vertically polarized to study cross polarization discrimination. The median isolations over about 155 feet were calculated along with the receiver geo-location for both polarizations. An exhaustive search was performed on all median data recorded with the two polarizations to determine coincident measurement locations. Locations within 100 feet of each other in the two data sets were considered to be coincident. For this work, polarization discrimination at a single point is defined as the change in median isolation when the polarization is changed from co-pol to cross-polarization. Its cumulative distribution function is shown in Figure 4. Half of the locations displayed a discrimination of less than 7.5 dB. At ten percent of the locations, the cross polarized signal was stronger than the co-polarized signal. Hence, polarization discrimination is not a reliable technique for increasing the isolation between a microwave system and PCS.

4.3 Antenna Front-to-Back Ratio

At the Empire State Building, measurements were recorded at two transmitter antenna azimuths, 29 and 203 degrees. Although the separation is not quite 180 degrees, measurements from this antenna combination can be used to estimate the realizable front-to-back ratio of the microwave antenna. Figure 5 shows measured isolation for receiver locations between 24 and 34 degrees azimuth. These are in the "main beam" of the 29 degree transmitter azimuth and the "back lobe" of the 203 degree transmitter azimuth. Regression lines are shown for the two sets of isolation. The distance dependence slopes are nearly identical with about a 20 dB offset between the two lines. This gives us a preliminary estimate of 20 dB for the realizable front-to back-ratio of the antenna measured at ground level. Its listed front-to-back ratio is 30 dB. The 10 dB degradation is caused by multipath scattering that has "filled in" the area behind the transmitter and perhaps also by the receiver not being in the boresight plane.

Hence, published microwave antenna discrimination factors must be used with caution when computing the obtainable isolation to a PCS system, even from a very high antenna location. It may be argued that the maximum obtainable antenna discrimination in such a scattering environment reaches an upper limit. This limit may be typified by the 20 dB obtained in this experiment. It may be further argued that the discrimination would decrease even more as the microwave antenna is lowered into the clutter. It may be appropriate to apply such corrections to directional PCS antennas as well. Suitable de-rating factors for different antennas and lower antenna heights should be investigated.

4.4 DISCUSSION

The results underline the differences between the comparatively well behaved microwave radio terrain propagation environment and the rapid short-scale variation of the PCS world. The terrain and the clutter in which the PCS system is embedded become very strong factors and dominate the isolation parameter, particularly at short distances. They also contribute to the high variability of the measured data.

A complex area such as New York City has some regularity in its plan layout, even though it may be very irregular in the third dimension. Thus, if building height data were available, it may be amenable to modeling close in. Further away, the terrain along the line-of-sight and the surface cover information, with the city appearing as a clutter factor, may give good results.

5 SUMMARY

A radiowave propagation experiment was performed to study spectrum sharing in the New York City region. It used a CW transmitter radiating from a parabolic antenna. This antenna was placed in two buildings where point-to-point microwave link could be used. The signal level was measured from a vehicle which traveled in New York, New Jersey, and Connecticut.

The results showed that the isolation measured between the microwave system and a personal communications system on the street depended only weakly on the distance. It depended strongly on the building shadowing and street orientation within the city. At greater distances, the topography, including intervening hills and the curvature of the earth which could shield the systems, played a strong role in providing isolation. The minimum isolation required for sharing the spectrum with PCS emitters is system dependent only and not related to distance in any way, It significantly exceeded the free-space value. It could be found even in the conventional main beam direction in locations surrounded by shadowing objects. Conversely, strong signals were often found well away from the main beam. Thus, there was measurable degradation of the microwave antenna discrimination. The data also showed that polarization discrimination cannot be depended upon to increase the isolation between point-to-point microwave links and PCS systems. Closer in, the isolation varied widely, with regions of strong signals popping up in larger shadowed areas. Hence, low power systems with low antenna heights and small cell sizes, on the order of a city block or less, would have a better probability of finding suitably isolated regions to operate in. This could be further enhanced by active monitoring of the isolation. Large cell, high-powered systems with high antennas may need to move well beyond the horizon to share spectrum.

Distance related purely statistical models, such as the Okamura-Hata and the Longley-Rice area model, under-predicted the results significantly. Their average curves of path loss lay close to the lower bound of the measured isolation. Even if some microwave antenna discrimination and statistical deviations are factored, these models would miss most sharable regions.

6 REFERENCES

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[3] Hata, M.: "Empirical Formula for Propagation Loss in Land Mobile Radio Services", IEEE Transactions of Vehicular Technology, Vol. VT-29, No. 3, Aug. 1980, pp. 317 - 325.

[4] Hufford, G., Longley, A., and Kissick, W. "A Guide to the Use of the ITS Irregular Terrain Model in the Area Prediction Mode", NTIA Report 82-100 (PB 82-217977), April 1982.

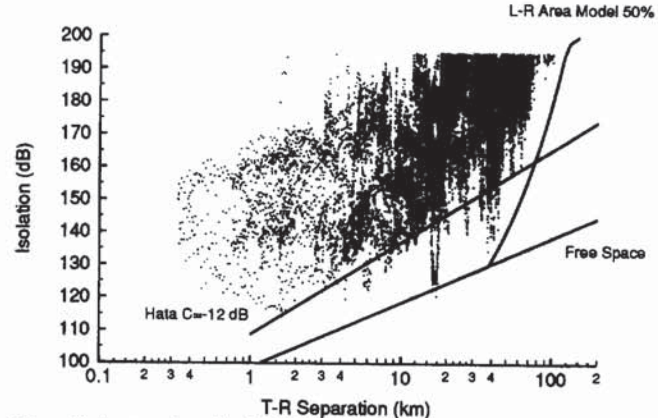

Figure 1: Scatter plot of Isolation (dB) vs. T-R Separation (km) for co-polarized measurement locations with the transmitter on the Empire State Building with an Azimuth of 203 degrees. Also shown are the free space, Hata, and Longley-Rice Area Prediction path loss models.

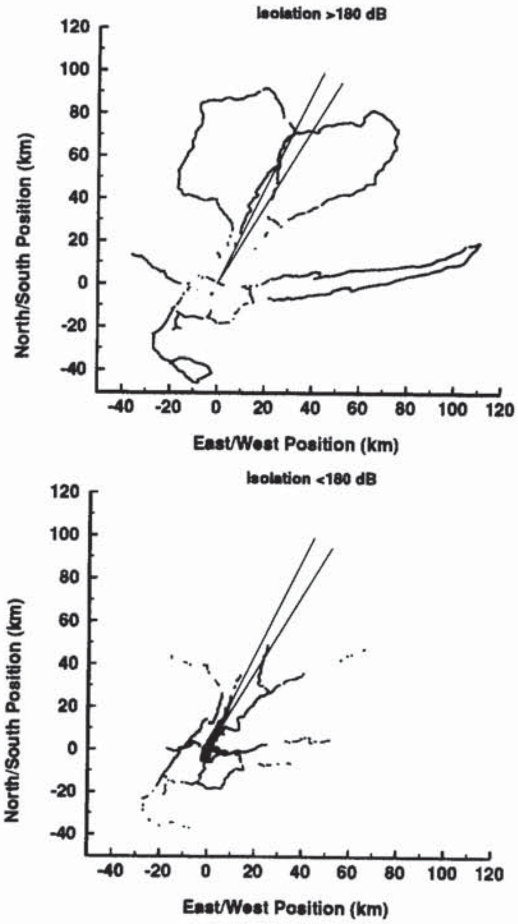

Figure 2: Drive-around plot of co-polarized measurement locations with the transmitter on the Empire State Building with an Azimuth of 29 degrees. The top plot (a.) shows regions of isolation >180 dB, and the bottom plot (b.) shows regions of isolation <180 dB.

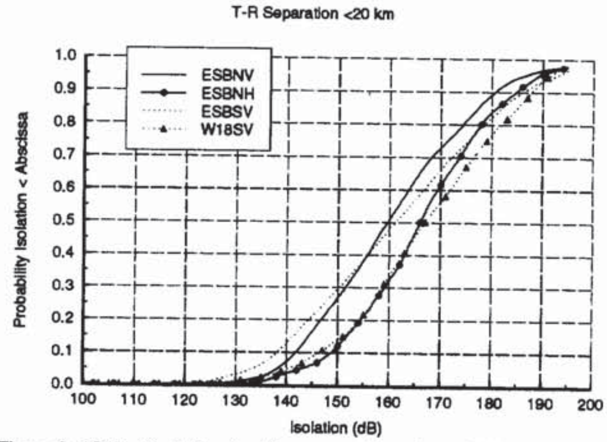

Figure 3: CDF of Isolation for all measured locations within 20 km of the transmitter. Each curver represents a different set of measurement data.

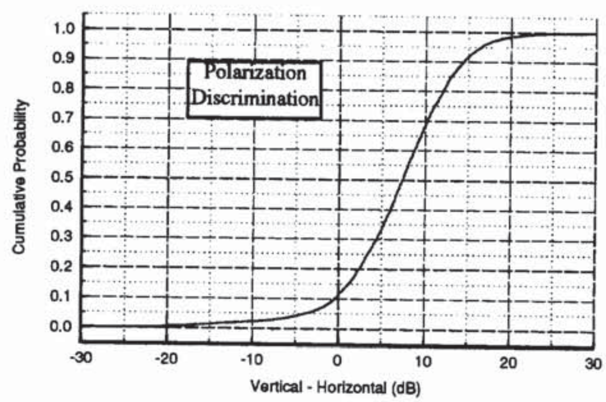

Figure 4: CDF of the measured difference between co-polarized and cross-polarized signal levels with the transmitter on the Empire State Building at an Azimuth of 29 degrees.

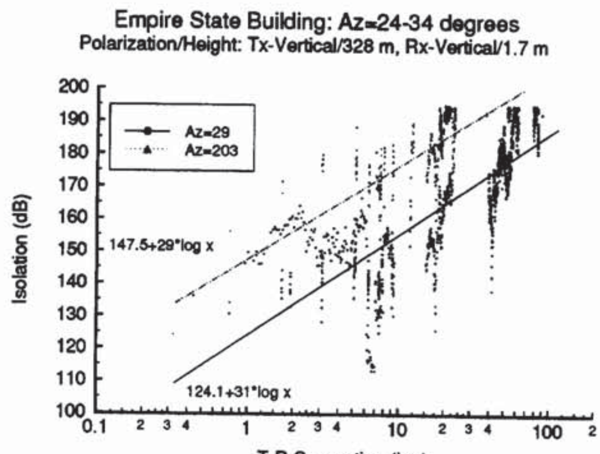

Figure 5: Scatter plot of Isolation (dB) for locations between 24 and 34 degrees azimuth with two different transmitter antenna boresight azimuths (29 and 203 degrees).