BUILDING PENETRATION LOSS FOR SLANT-PATHS AT L-, S- AND C-BAND

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ABSTRACT

This report describes measurements made to determine the statistics of building entry loss, for slant paths at frequencies between 1 and 6 GHz. The work described was funded under the S@TCOM programme of the British National Space Centre (BNSC).

Measurements of building penetration loss have been made at one office and three domestic sites in England. Tests were made at 1.3 GHz, 2.4 GHz and 5.7 GHz, and a tethered balloon was used to explore a range of elevation angles. A total of 12,450 spot measurements were made, at 11 receiver locations.

The mean measured value of penetration loss, averaged over all frequencies and test locations, was 11.2 dB. The mean loss at the highest frequency was some 3.5 dB greater than that at the lowest frequency. Some dependence was found on elevation angle at the two higher frequencies.

INTRODUCTION

Satellite spectrum planners have an increasing requirement for accurate date on building penetration loss, both to determine the extent of indoor coverage that may be possible, and to evaluate the severity of potential interference to satellite receivers from indoor systems such as wireless LANs.

Much effort has been expended in the last decade in the measurement and modelling of building entry loss and indoor coverage in respect of terrestrial systems, with particular emphasis on the mobile telephony frequencies around 900 MHz and 1.8 GHz.

For the European satellite system designer, however, much of this data is of limited use. A fundamental problem is that there is little data on the elevation dependence of such losses. While, in general, higher elevation paths will suffer from lower diffraction losses due to local clutter, it has been suggested that building penetration losses will be higher due to the increased likelihood of intersecting building material.

A further limitation is that much of the present data is based on measurements made within US or Japanese office or laboratory buildings, which are unlikely to be representative of the majority of UK or European building stock, particularly when domestic buildings are also considered. Where measurements concerning domestic buildings are available, it seems that the construction of those examined may be lighter than is generally the case in Europe.

PREVIOUS WORK

A moderate amount of experimental data has been published (1-4) regarding building penetration loss. Much of the recent measurement work has been aimed at informing debate within the ITU and CEPT regarding the constraints that should be applied to licence-exempt WLAN devices operating at 5 GHz.

Average values of penetration loss, measured at 5 GHz in offices and laboratory buildings in Europe have been found to be in the range 12-22 dB. In particular, a set of measurements (3), made at an office block with a helicopter found an average loss of 19.1 dB with no monotonic dependence on elevation angle.

One set of measurements (4) in US domestic buildings reported average losses at 5 GHz of some 14 dB for horizontal paths.

BUILDING STATISTICS

A small amount of effort within the project was devoted to an attempt to determine the statistics of UK building types, particularly with respect to age and construction.

Such statistics proved remarkably difficult to obtain, particularly for non-domestic buildings. However, a 5-category classification has been drawn up, based on UK Government statistics.

It appears that roughly 20% of current housing stock falls into each of the categories: ‘pre-1919’, ‘inter-war’, 1945–1962, 1962–1984 and ‘contemporary’.

It had initially been hoped to undertake measurements at sites representing each category; the limited time available, and the practicalities of site selection ensured that this was not possible. It is the case, however, that the measurements made cover a range of common European building types not considered in existing measurements.

EXPERIMENTAL METHOD

Test transmitters

The measurements were narrowband, using a CW source. To minimise cost and balloon-lifting requirements, the RF sources consisted of simple crystal-controlled transmitter modules with an output of around 1 Watt.

These RF sources drove low-gain antennas (end-fed dipoles) to avoid complications of antenna pointing. To avoid distortion of the radiated field, the radio frequency source assembly was self-contained, powered by a small lead-acid battery.

The specific frequencies chosen for the measurements were 1300 MHz, 2410 MHz and 5760 MHz.

Balloon platform

The transmitter assemblies were suspended below a helium balloon, which could be raised and lowered to explore the geometries required.

It had initially been proposed that the precise position of the balloon at all times would be recorded by means of a differential GPS (DGPS) receiver. Following discussions with the balloon manufacturers, it was decided to use a rather larger balloon than originally intended (a 'blimp' of around 20' in length rather than the 6' sphere originally proposed). This arrangement provided sufficient stability to dispense with the DGPS equipment.

Receive equipment

The receiver, located within the building under investigation, consisted of an Anritsu MS2663A spectrum analyser, interfaced to a PC for control and logging. As with the transmitter, a largely omnidirectional aerial was used at the receiver, as it was expected that much of the received power would be due to scattered components. This antenna was moved along a track under computer control, to allow spatial averaging of measurements.

The input to the spectrum analyser was switched between the measurement antenna and a reference antenna located outside the building (in line of sight to the balloon). This arrangement increased the overall measurement accuracy as only relative measurements were made, with changes due to variations in transmitter power, transmit antenna alignments, etc., rendered irrelevant.

Experimental procedure

Measurements were made at four sites in the southern UK – a 1980's 3-story office building, and houses from the Victorian (1880), Edwardian (1905) and 1960's periods.

At each site, a succession of measurement 'runs' was made to explore different elevation angles and locations within the building. The balloon was raised to increase the elevation angle, and was tethered closer to the building as larger elevation angles were sampled.

Within the building, the received field strength was sampled at a large number of closely separated locations, to average the expected small-scale (multipath) fading. The unavoidable movement of the balloon also served to average such fading.

MEASUREMENT ANALYSIS & RESULTS

Introduction

The power levels received at the reference and test antennas were stored on the logging PC as XML files. The structure of each record includes the measurement frequency, power level, aerial track position, coaxial switch setting and a timestamp. The use of XML allowed for considerable flexibility in post-processing. Each 'measurement' consisted of a set of 50 samples, taken from the test antenna at 2 cm intervals along the 1 metre track. For each of these samples, a corresponding power measurement was made from the (immobile) reference antenna.

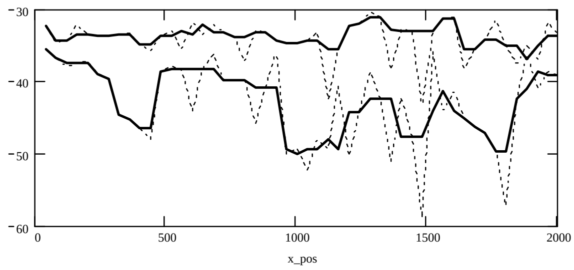

Figure 1: Time series of power measurements

A complete time series from one such measurement (at 1.3 GHz) is shown in Figure 1, showing both raw data (dotted), and a sliding average over three samples. It can be seen that not only is there the expected variation in the power received at the 'test' antenna (lower curves), but also substantial variation in the 'reference' measurements. The latter variation is due to the unavoidable variation in the instantaneous balloon position, and reflects the impact of multipath effects, transmit antenna pattern variation and range variations (in approximate order of severity).

To eliminate these effects, and also to eliminate the fast fading experienced at the test antenna, the two sets of 50 samples made at each measurement point were averaged prior to correction and analysis. The detail contained in these individual time-series is, however, of interest, and is considered further below.

As has been discussed above, the reference and test antennas must obviously be in different locations. As the difference in these positions will not be an insignificant proportion of the path length from the balloon, it is necessary to correct the measured results to account for both the difference in range, and for the difference in apparent elevation angle (and hence antenna gain) between the two antennas.

Range correction

For the majority of measurements, the range from the balloon to the test antenna was greater than that to the reference antenna. The geometry of each measurement was carefully recorded using tape measures, and the difference in range for each balloon height determined.

It was then trivial to apply a correction to the reference antenna results, to correct them to the hypothetical free-space value at the test antenna.

Antenna pattern correction

The need for antenna pattern correction arises from the difference in elevation between the test and reference antennas. The intention is not to correct the measurement data so that it represents (for example) isotropic received power, but simply to account for the difference in gain of the two antennas for each balloon height. This will clearly be zero for the 'zero elevation' case, assuming the two antennas are at the same height. As the balloon's height increases, however, so the difference in elevation angle (and hence gain) at the two antennas will increase. It was therefore necessary to correct the powers measured at the reference antenna to represent the power that would have been measured by an antenna in free space at the test location.

PENETRATION LOSS RESULTS

Mean penetration loss values

Following the corrections described above, a data set giving the mean penetration loss for each test location was obtained. The CDF of these results is shown in Figure 2, and represents the statistics of mean local loss with respect to all 11 receiver locations, at all elevation angles.

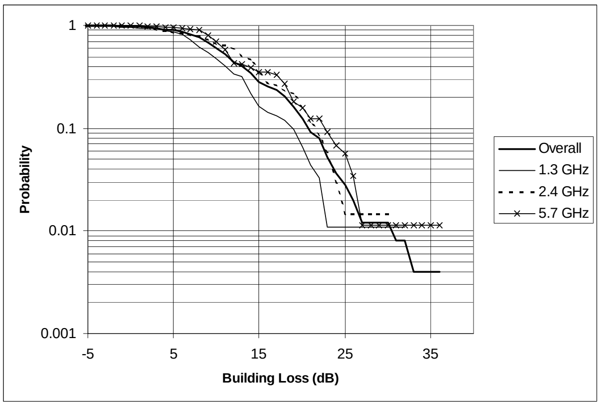

Figure 2: Overall statistics of building penetration loss

The mean value of building penetration loss, at all frequencies, is 11.2 dB. The dependence on elevation angle, frequency and test location is discussed below.

Elevation angle dependence

Measurements made at all locations were examined with respect to elevation angle, at each frequency. A typical set of results (those for 2.4 GHz) is shown in Figure 3.

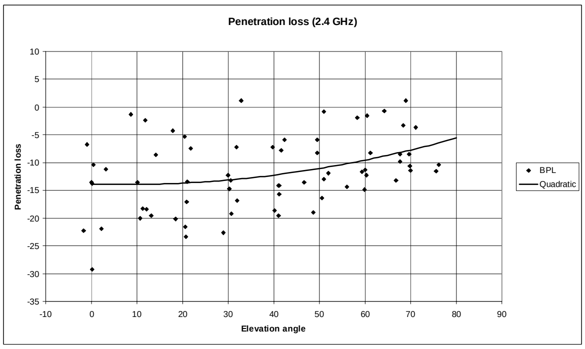

Figure 3: Elevation dependence 2.4 GHz (all locations)

Polynomial curves fitted to the measurements are compared in Figure 4.

The results at 1.3 GHz show an anomalous increase in the penetration loss for higher elevation angles. Examination of the measurement data shows that this effect is due to one set of measurements, made at the Cobham site. The effect of excluding this data is shown in the dotted curve.

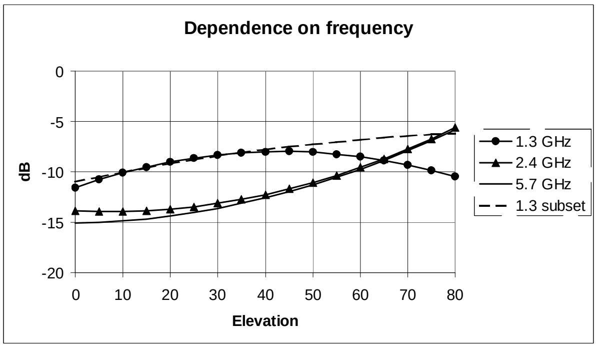

Figure 4: Mean values for each frequency compared

It can be seen that, except at the lowest frequency, there is a slight decrease in penetration loss for higher elevation angles.

Frequency dependence

The CDF curves given in Figure 2 show a slight frequency dependence in the results. Mean values of penetration loss are 9.2 dB at 1.3 GHz, 11.2 dB at 2.4 GHz and 12.7 dB at 5.7 GHz.

Examining the frequency sensitivity of the elevation dependence (Figure 4) shows near identical results for 2.4 and 5.7 GHz. As noted above, the tendency for loss to decrease at higher elevation angles is not evident at the lower frequency.

Dependence on building floor

Figure 5 illustrates the variation of penetration loss with the floor on which the receiver is located (2.4 GHz Measurements are shown).

Some dependence on floor is apparent, with the ground floor results generally showing greater loss than those for the second floor. It should be borne in mind, however, that only one set of measurements was made on a second floor, and the location was a converted roof space, used as a home office.

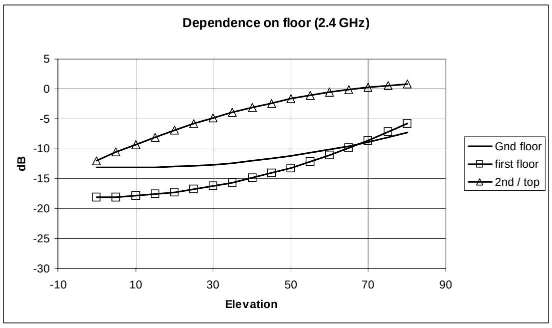

Figure 5: Loss dependence on building floor (2.4 GHz)

Fading statistics

The main results from this study are the values for mean local penetration loss. To allow the determination of link budgets, or to ensure specific levels of protection against interference, the fading characteristics of the indoor signals must be known. The antenna moved along a one metre track, which represents around four wavelengths at 1.3 GHz and 20 wavelengths at 5.7 GHz. In the multipath-rich indoor environment, it would be expected that the fading statistics at this scale would show Rician or Rayleigh distributions for line of sight (LOS) and non line of sight (NLOS) cases respectively.

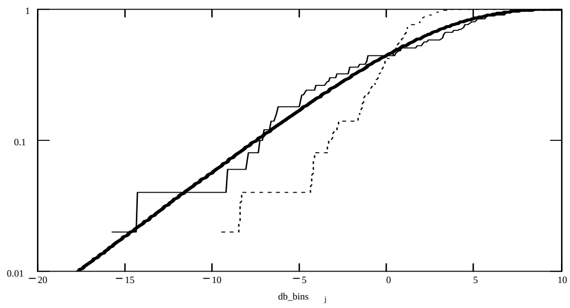

Figure 6: Small-scale fading – Comparison of 'Test' (solid) and 'Reference' (dotted) measurements with Rayleigh statistics

Examination of the measurements (Figure 6) shows that the 'test' antenna measurements do follow a Rayleigh distribution: this would be expected as virtually no measurements were LOS.
The statistics for the 'reference' measurements were also examined, and found to follow a distribution closer to the Rician.

CONCLUSIONS & FURTHER WORK

Previous measurement campaigns have reported mean values for building penetration loss of between 12 and 22 dB at around 5 GHz.
The current campaign has concentrated on typical UK domestic building stock, and shows a mean penetration loss of 11.2 dB, averaged over the three frequencies investigated, 1.3 GHz, 2.4 GHz and 5.7 GHz.
Much of the previous work has been aimed at determining the levels of interference likely to be caused to satellite systems from licence-exempt systems operating at 5 GHz. The results reported here suggest that the degree of protection available from building losses may be somewhat less than has been assumed.
A slight frequency dependence was found in the measurements, with the mean loss at 1.3 GHz being 3.5 dB less than at 5.7 GHz.
The 2.4 GHz and 5.7 GHz results showed some elevation dependence, with building loss values falling by some 10 dB over an 80 degree range. This dependence was not evident in the 1.3 GHz results. It is noteworthy that the decrease in building loss with elevation runs counter to the assumptions made in some previous models. It may be that this behaviour is characteristic of domestic buildings, where floors and ceilings are typically of light wooden construction.
It is hoped that the results presented in this report will be of use both in the determination of link budgets for systems aiming to provide a degree of indoor coverage, and in the estimation of inter-system interference levels.
The narrowband measurements reported here have briefly considered the fading regime for signals penetrating buildings. A follow-on study, examining wideband channel characteristics is currently in progress also funded under the S@TCOM programme. That study will examine the wideband characteristics of the satellite-to-indoor channel.

ACKNOWLEDGEMENT

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