Indoor Radiowave Propagation Measurements at Frequencies up to 20 GHz

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Abstract: Wideband radiowave propagation measurements were performed within a building at 2, 5 and 17 GHz using a vector network analyser. The exponent of the path-loss law $n$ and the statistics of the rms delay spread were evaluated for line-of-sight (LOS) and obstructed (OBS) paths. Values of $n$ for LOS paths were similar for all three frequencies whilst increasing attenuation with frequency was observed for OBS paths. Mean rms delay spread values were found to decrease with frequency.

I. INTRODUCTION

The advent of personal communication systems (PCS) and high bit-rate wireless local area networks (WLANs) has led to increasing study of the wideband propagation characteristics of radiowaves within buildings. Time domain measurements of rms delay spread and path-loss in indoor environments have previously been reported by several authors at frequencies up to 4 GHz [1,2]. More recently, frequency domain measurement systems have been used to provide both time and frequency domain statistical data at frequencies up to 11 GHz [3-5].

This paper describes experiments performed within a building at 2, 5 and 17 GHz using a frequency domain measurement system incorporating a vector network analyser. The aim of the experiments was to evaluate path-loss and the statistics of the rms delay spread in a typical PCS/WLAN environment and to compare the results for different frequencies.

II. MEASUREMENT SYSTEM

The block diagram of the measurement system is shown in Fig. 1. At the heart of the system lies a vector network analyser (VNA) which is used to obtain samples of the indoor radio channel transfer function. A swept sine-wave test signal is generated by a 2-20 GHz synthesised source and split into test and reference channels by a power splitter. The reference channel is fed to a frequency converting test set via a 25 m length of low-loss cable. The test set harmonically samples the received signal, the third i.f. of which is interpreted by the VNA for phase and magnitude data by comparison with the reference channel. The source power may be varied although sufficient power must be generated to overcome reference cable loss whilst providing a minimum of -25 dBm required by the test set to maintain phase lock. The test channel is amplified by a wideband amp with 18 dB gain and a maximum output power of 25 dBm. Transmit and receive antennas are both bi-conical omnidirectional, chosen for their wide bandwidth. The receive antenna is connected directly to the test set. Both antennas are mounted on stands at a height of 1.8 m.

Using the test set in the configuration shown provides the maximum dynamic range (approx. 105 dB) which is necessary to achieve the signal to noise ratio required for measurement of the deep frequency selective fading likely to occur in the indoor radio channel. A maximum of 501 individual frequencies may be measured by the VNA within a specified bandwidth between 2 GHz and 20 GHz. The measurement system is controlled by a 486 PC compatible via a GPIB interface. Measurement data is downloaded to the PC for analysis.

Fig. 1. Block diagram of the frequency domain measurement system.
III. EXPERIMENTAL PROCEDURE

Measurements were performed in three frequency bands: 2-2.5 GHz, 5-5.5 GHz and 17-17.5 GHz. Before the measurements were carried out the system was carefully calibrated at the frequency bands of interest to compensate for the phase and amplitude variations caused by the amplifier, cables, measurement equipment and antennas. The influence of cable bend and cable replacement were neglected.

Measurements were performed within the Faraday Tower building at the University College of Swansea, Wales. A plan of the area in which measurements were taken showing approximate transmit and receive antenna locations is given in Fig. 2. The locations of doors and windows are marked. The large Communications Lab (7.4 x 7.1 x 2.8 m) is an open plan environment with several rows of tables running along the centre of the room with computer terminals on each and various desks, filing cabinets and shelving placed around the walls. Measurements were also taken in the adjoining corridor (1.8 x 21.7 x 3.0 m). In order to maintain a static environment it was ensured that no personnel were present within the Communications Lab or corridor whilst measurements were being taken.

Three sets of measurements were taken, with the transmitter, i.e. the source, amp and transmit antenna, placed at a different location for each set. The receiver, consisting of the VNA, test set and receive antenna, was moved to a new position for each measurement. A measurement consists of a single sweep over each of the three frequency bands. The measured frequency responses were stored on the PC for subsequent analysis and the antenna separation recorded. The measurements can be divided into two cases: those where a direct line-of-sight (LOS) existed between transmit and receive antennas and obstructed (OBS) situations where up to two walls separated the transmitter from the receiver.

IV. ANALYSIS OF RESULTS

The magnitude (dB) and phase (degrees) of a typical frequency response as measured by the VNA are presented in Fig. 3. Notches in the magnitude clearly illustrate the frequency selective nature of fading in the indoor channel. The phase is mostly linear except for large phase shifts which occur when deep fades are present.

The time domain response may be obtained from the measured samples of the frequency domain response using several possible conversion methods [6]. The most well-known of these is the Inverse Fast Fourier Transform (IFFT) which has been chosen in this study for its high speed of operation and ease of implementation within the analysis software. A sweep bandwidth of 500 MHz and a 1024-point FFT provide a time domain resolution of 1 nS. The magnitude of the computed time domain response for the frequency response of Fig. 3 is given in Fig. 4. A dominant LOS component and many multipath components with various propagation delays can be clearly seen.

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Fig. 2. Plan of the measured indoor environment.
respectively. Using linear regression analysis the minimum mean square error (MMSE) line was calculated for the LOS cases. From the analysis, similar values of $n$ were obtained for all three frequencies. For OBS measurements the additional attenuation caused by walls in the propagation path led to values of received power which are considerably less than those for LOS cases at equivalent distances. From examination of Figs. 5 to 7 it can be seen that this attenuation also increases with frequency.

B. RMS Delay Spread

The rms delay spread provides a measure of the time dispersion in multipath channels [7] and is an important parameter for evaluating the performance of digital systems [8]. The mean and standard deviations of the rms delay spread values computed from time domain responses for both LOS and OBS cases are given in Table I. The maximum rms delay spread measured was 59 nS.

<table>
<thead>
<tr>
<th>Location</th>
<th>2-2.5 GHz</th>
<th>5-5.5 GHz</th>
<th>17-17.5 GHz</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mean</td>
<td>s.d.</td>
<td>mean</td>
</tr>
<tr>
<td>T1</td>
<td>34.5</td>
<td>13.2</td>
<td>14.4</td>
</tr>
<tr>
<td></td>
<td>39.6</td>
<td>10.5</td>
<td>22.0</td>
</tr>
<tr>
<td>T2</td>
<td>37.5</td>
<td>11.8</td>
<td>14.8</td>
</tr>
<tr>
<td></td>
<td>37.7</td>
<td>12.0</td>
<td>21.2</td>
</tr>
<tr>
<td>T3</td>
<td>49.0</td>
<td>5.4</td>
<td>15.7</td>
</tr>
<tr>
<td></td>
<td>37.6</td>
<td>17.0</td>
<td>22.1</td>
</tr>
</tbody>
</table>

The values of mean rms delay spread (10-50 nS) are typical of those found in similar indoor environments [2-4]. For location T1 the LOS values are very similar to those for location T2 despite the quite different placing of the transmitter within the Communications Lab. In both cases mean values of rms delay spread reduce with increasing frequency, as was also observed in [4]. Values of rms delay spread at 17-17.5 GHz are approximately 30% of those at 2-2.5 GHz. For location T3, LOS values were consistently higher at all three frequencies. For locations T1 and T2, OBS values were higher than LOS.

Given the above results it is possible to speculate on how the choice of operating frequency may influence the performance of a PCS or high bit-rate WLAN in an open-plan environment. Path loss at 2 GHz in OBS situations is lower than that at 5 or 17 GHz thereby giving a greater coverage. However, since mean rms delay spread decreases with frequency it may be preferable to operate a high bit-rate system at 17 GHz.
Fig. 5. Received power against distance for the 2 GHz measurements. The minimum mean square error fit to the LOS cases is shown.

Fig. 6. Received power against distance for the 5 GHz measurements. The minimum mean square error fit to the LOS cases is shown.

Fig. 7. Received power against distance for the 17 GHz measurements. The minimum mean square error fit to the LOS cases is shown.
V. SUMMARY AND CONCLUSIONS

In order to characterise the indoor radio channel, measurements were performed at 2, 5 and 17 GHz using a vector network analyser. Frequency responses were obtained for three transmitter locations and sixty receiver locations in an open-plan laboratory and adjoining corridor. The Inverse Fast Fourier Transform was used to convert the frequency domain data to corresponding time domain responses. The exponent of the path-loss law $n$ and the statistics of the rms delay spread were evaluated for line-of-sight (LOS) and obstructed (OBS) paths. Values of $n$ for LOS paths were very similar for all three frequencies whilst increasing attenuation with frequency was observed for OBS paths. Mean rms delay spread values were found to decrease with frequency for the open plan environment.

The frequency domain measurement system described in this paper has provided useful results relating to the characteristics of wideband radiowave propagation within buildings at 2, 5 and 17 GHz. These results have implications for the design of indoor wireless communication systems.

VI. ACKNOWLEDGEMENTS

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VII. REFERENCES


