

## DELAY SPREAD AND RECEIVED POWER MEASUREMENTS WITHIN A BUILDING AT 2 GHz, 5 GHz AND 17 GHz.

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### INTRODUCTION

Spectrum at microwave frequencies has recently been allocated within Europe and the United States for the evolving high bit rate wireless local area networking standards, namely ETSI HIPERLAN and FCC SUPERNET [1,2]. Installation and movement of networked PC's and workstations will no longer be restricted by cabling requirements. This technology will also find other applications including the transmission of high quality digital video within television studios [3].

In order to design a radio-based high bit rate data transmission system the multipath time dispersion characteristics of the radio channel, and in particular the rms delay spread, are an important consideration [4,5].

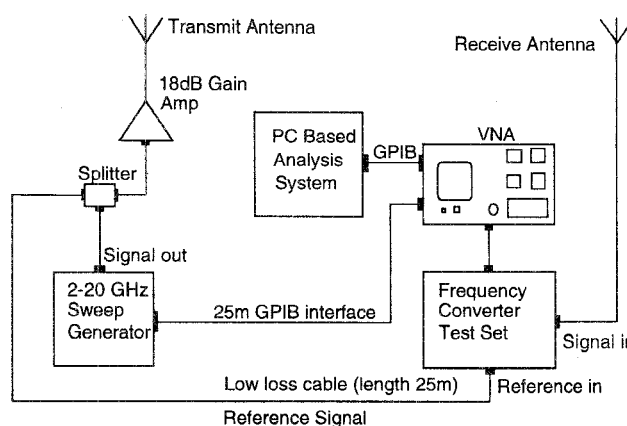
For the prediction of system coverage and spectrum planning the effect of the indoor environment on the received signal power at different locations within a building must also be considered.

Very few results have been published, however, for actual radiowave propagation measurements obtained within buildings at these frequencies. Time domain measurements have previously been reported by several authors at frequencies up to 4GHz [6,7]. More recently, frequency domain measurement systems have been used to provide both time and frequency domain data up to 17GHz [8,9].

Rms delay spread and received power results are presented in this paper for measurements at 2GHz, 5GHz and 17GHz covering a wide variety of typical indoor scenarios including line-of-sight transmission within a room, obstructed transmission within a room and transmission between rooms.

### MEASUREMENT SYSTEM

The block diagram of the measurement system is shown in Figure 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.



*Figure 1. Block diagram of the frequency domain measurement system.*

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 25m 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 -25dBm required by the test set to maintain phase lock. The test channel is amplified by a wideband amp with a maximum output power of 25dBm. The transmit and receive antennas are both biconical omnidirectional, chosen for their wide bandwidth. The receive antenna is connected directly to the test set. The antennas are mounted on variable height stands.

Using the test set in the configuration shown provides the maximum dynamic range (greater than 105dB) 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 2GHz and 20GHz. The measurement system is controlled by a PC compatible via a GPIB interface. Measurement data is downloaded to the PC for analysis.

## MEASUREMENT SITES

The measurements reported here were taken on the 6th floor of the Faraday Tower building at the University of Wales Swansea. The Faraday Tower (built c. 1965) is a seven storey tower block with a steel framed reinforced concrete construction, exterior curtain walling, block interior walls and concrete floors. The 6th floor is divided into a number of offices of various sizes, two electronics laboratories and a large open plan office/CAD laboratory. These rooms are all interconnected by a single corridor.

Referring to Figure 2, the primary measurement locations were a medium size office referred to henceforth as Room A, the large CAD laboratory referred to as Room B and the adjoining sections of corridor.

The furniture within Room A comprises several desks, wooden bookshelves and a single metal filing cabinet located towards the centre of the room. Room B contains desks, tables, computer workstations, hardboard partitions, several metal filing cabinets and a large set of metal bookshelves. The location of each of these items is marked on Figure 2 with the filing cabinets and partitions emphasised.

Three main series of measurements were taken. For the first series the transmitter was placed at the centre of Room A, and measurements were taken at various random receiver locations within Room A and the adjoining corridor. For the second and third series, transmitter locations within Room B were chosen and measurements taken for a number of random receiver

locations within the room. Transmit and receive antennas were varied between set heights of 1.2m and 1.8m. The height of 1.8m placed the antennas above all furniture except the large metal bookshelves and hardboard partitions. The height of 1.2m brought filing cabinets, computer workstations and other items of office furniture within the beamwidth of the antennas. The total number of receiver locations was one hundred and eighty.

## ANALYSIS OF RESULTS

The magnitude (dB) of a typical frequency response as measured by the VNA is presented in Figure 3. Notches in the magnitude clearly illustrate the frequency selective nature of fading in the indoor channel.

The time domain response is obtained from the measured samples of the frequency domain response using the inverse fast Fourier transform (IFFT) [10]. A sweep bandwidth of 500MHz provides a time domain resolution of approx. 2ns. The magnitude of the computed time domain response for the frequency response is also given in Figure 3. A dominant LOS component and many multipath components with various propagation delays can be clearly seen.

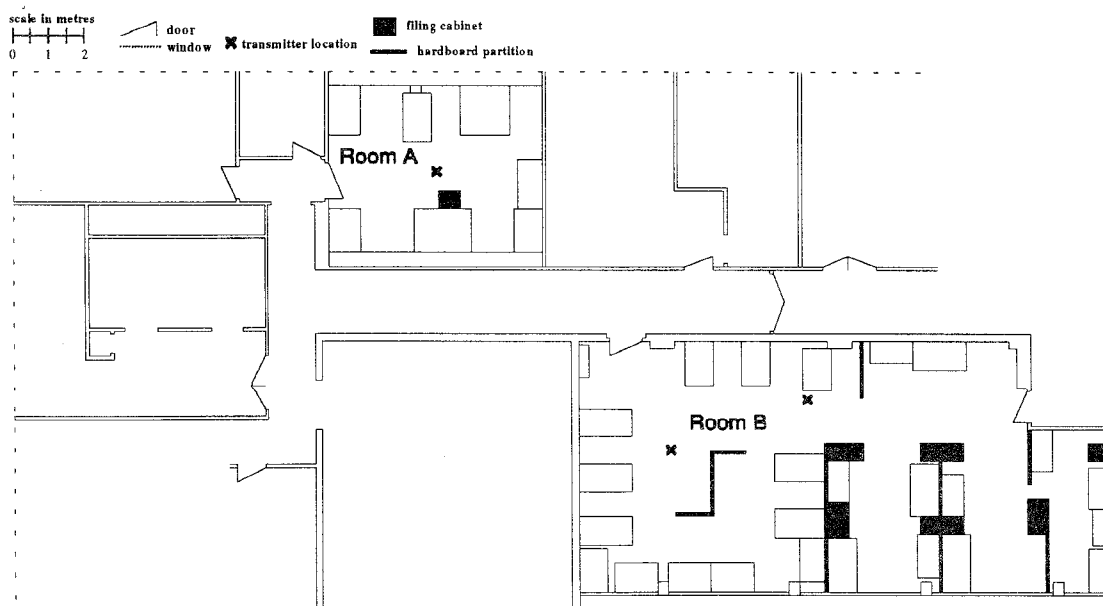


Figure 2. Plan of the measured indoor environment.

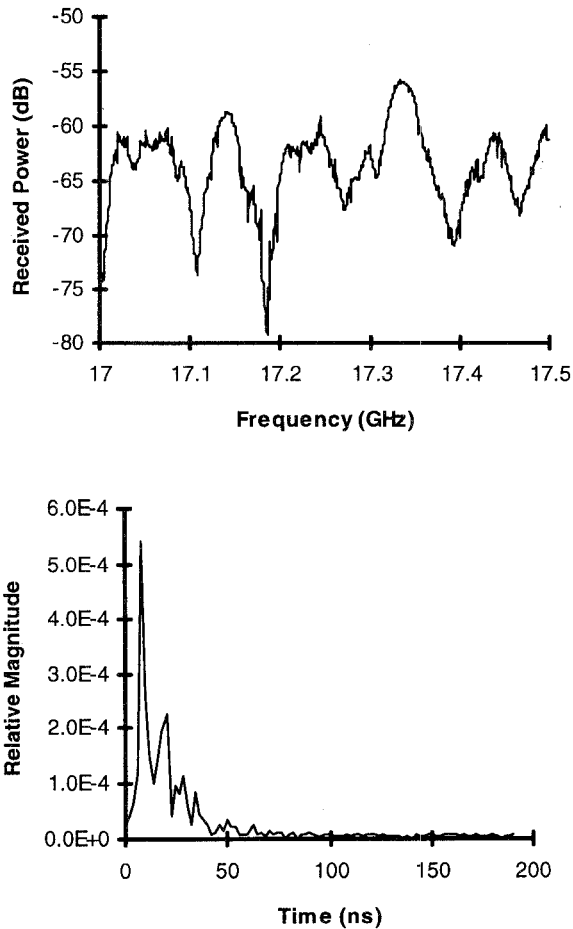


Figure 3. The magnitude (dB) of a typical measured frequency response and its corresponding time domain response.

**Rms Delay Spread**

Figures 4 to 7 present cumulative distributions of rms delay spread for measurements at the three frequencies 2GHz, 5GHz and 17 GHz. These values compare favourably with those of other published measurements at similar frequencies [9].

Since the rms delay spread data was not normally distributed it was necessary to employ non-parametric statistical analysis [11].

For all measurements, a significant increase of rms delay spread was found between 2GHz, 5GHz and 17GHz. This can be clearly seen in Figure 4 and Figure 5 which show cumulative distributions for measurements in Room A and Room B respectively where a clear line-of-sight (LOS) path, completely free of obstructions, was present between the transmitter and receiver. The two figures also indicate larger rms delay spreads in Room B than Room A. This was confirmed by the statistical analysis. Given that Room

B is somewhat larger than Room A the conclusion may reasonably be drawn that room size is a contributory factor in the measured values of rms delay spread.

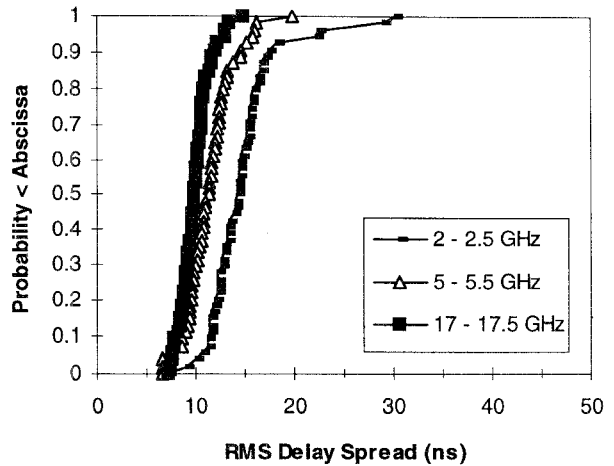


Figure 4. Cumulative distribution of rms delay spread for LOS measurements within Room A.

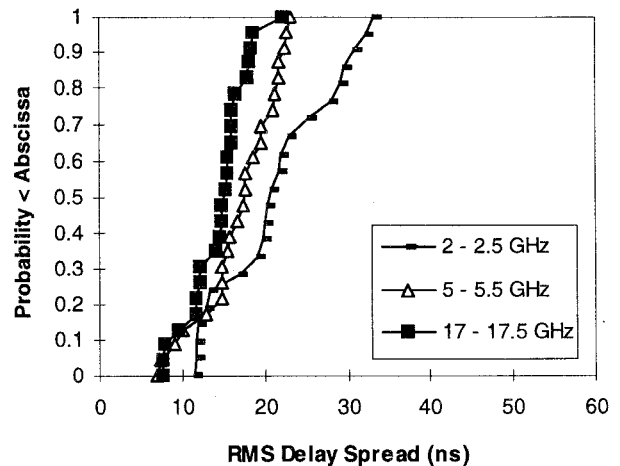


Figure 5. Cumulative distribution of rms delay spread for LOS measurements within Room B.

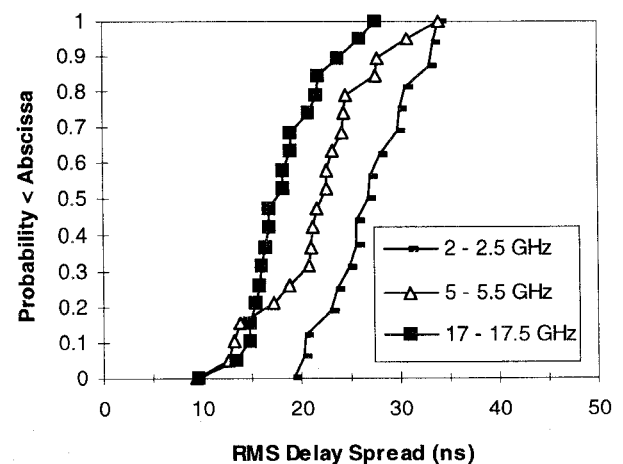
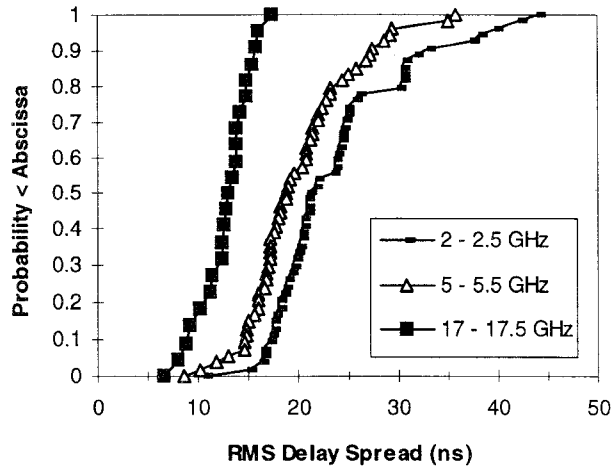


Figure 6. Cumulative distribution of rms delay spread for OBS measurements within Room B at an antenna height of 1.2m.



**Figure 7.** Cumulative distribution of rms delay spread for locations where the signal has passed through a wall.

The effect of obstruction of the direct path caused by different types of furniture within Room B was examined. Figure 6 present rms delay spreads for obstructed (OBS) measurements within Room B at an antenna height of 1.2m. It was found that obstructions produced a significant increase in rms delay spread, as can be seen from comparison of Figure 6 with Figure 5. The metal filing cabinets and bookshelves, in particular, caused a significant increase when blocking the direct path. From the statistical analysis, the hardboard partitions appeared to produce a very slight increase at 2GHz but not at 5GHz or 17GHz, however there were too few measurements of this type to draw any firm conclusions.

Antenna height in itself was found not to make a difference, however there is an increased incidence of blocking by furniture at the lower antenna height of 1.2m.

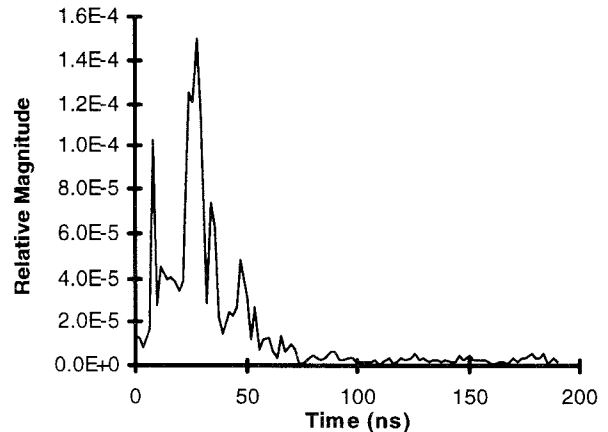
No significant difference was observed between rms delay spread measured from the two separate transmitter locations within Room B.

Figure 7 provides the rms delay spread for measurements taken in the corridor outside Room A with the transmitter located within Room A. Hence, for these measurements the direct signal has passed through a wall. By comparison with Figure 4, a significant increase can be seen at all three frequencies.

The effect of metal furniture was seen clearly in Room A where a region of higher delay spread occurred behind the metal filing cabinet. Figure 8 is a typical time domain response from this region and may be compared to Figure 3, a LOS measurement taken elsewhere within Room A for the same separation between transmit and receive antennas. The direct path

is severely attenuated and reflections dominate the response. Figure 8 has a rms delay spread of 26ns compared to 10ns for Figure 3.

A correlation study was performed for the rms delay spread and the distance between the transmit and receive antennas for measurements where the transmitter and receiver were located within the same room. Low values of correlation coefficient clearly indicated that the measured rms delay spread was generally independent of the distance between the transmitter and receiver.



**Figure 8.** Time domain response from a location totally obstructed by a metal filing cabinet.

### Received Power

A value of average received power for each measurement was obtained by averaging across the frequency domain data.

The average received power against distance on a logarithmic scale for measurements where the transmitter was located at the centre of Room A is plotted in Figures 9 to 11. The results are grouped according to the number of walls blocking the direct path between the transmitter and receiver. For each set of values a MMSE line has been calculated and plotted.

The values for the path-loss exponent  $n$  and the correlation coefficient  $r$  are given.

All values of  $n$  calculated for LOS cases are close to 2.0, the value predicted for free-space. This is consistent with previous and published results [8,9].  $n$  can be seen to increase after the signal has passed through one wall and increase again after passing through a second wall. The results for one wall are scattered over a short distance, however, leading to a low correlation with the MMSE line. To give some indication of the characteristics a line has still been plotted.

The additional signal attenuation caused by each wall may be seen as a downward step between the MMSE lines. The height of this step increases with frequency.

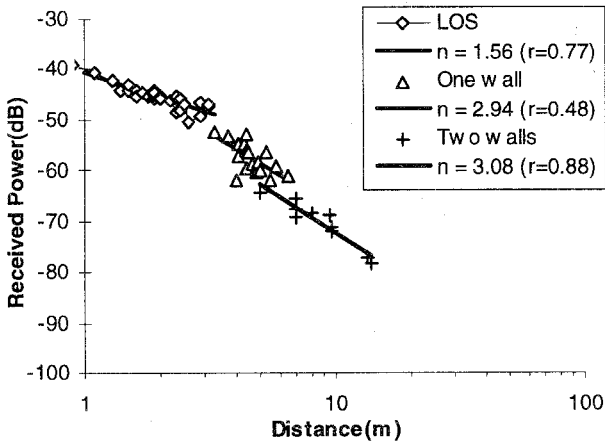


Figure 9. The effect of walls on the average received power at 2GHz

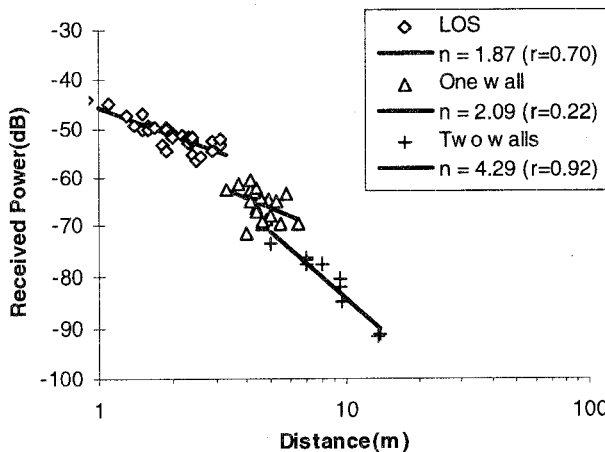


Figure 10. The effect of walls on the average received power at 5GHz

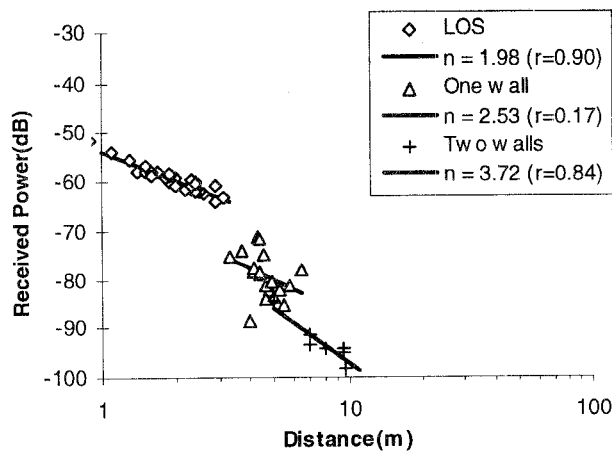


Figure 11. The effect of walls on the average received power at 17GHz

Measurement results from both Room A and Room B were used to determine the effect of metallic furniture on the received power measurements. In Figure 12, measurements taken at 17GHz where a filing cabinet blocked the direct path between transmitter and receiver were compared to LOS results for the same distance. The additional path loss caused by the filing cabinet ranged from 1dB to 13dB and is independent of transmitter-receiver separation, the distance from the transmitter to the filing cabinet and the distance from the filing cabinet to the receiver.

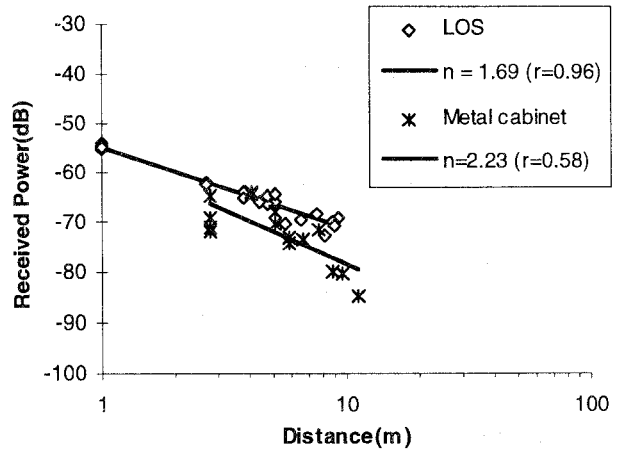


Figure 12. The effect of metal furniture on the average received power at 17GHz.

SUMMARY AND CONCLUSIONS

Comparative measurements of rms delay spread and received power were taken at 2GHz, 5GHz and 17GHz using a vector network analyser. Frequency responses were obtained for three transmitter locations and one hundred and eighty receiver locations on the sixth floor of the Faraday Tower building at the University of Wales Swansea.

Non-parametric statistical tests were performed on the rms delay spread data from which the following conclusions may be drawn.

The rms delay spread was found to decrease significantly with increasing frequency between the three bands measured.

The rms delay spread for a transmitter and receiver located within the same room was greater in a larger room but independent of the distance between the transmitter and receiver and the location of the transmitter.

Walls and metal furniture were found to significantly increase the rms delay spread. Inconclusive results were seen for hardboard partitions.

Measurements of received power have been presented for locations where the direct signal path has been obstructed by up to three walls and locations where a metal filing cabinet blocked the direct signal path.

The received power was dependent not only on the transmitter power and distance from the transmitter to the receiver but also on the operating frequency and the nature of the signal path. Obstruction by walls and metal furniture was found to be a primary factor influencing the received power and therefore the range of a wireless indoor data system.

Further work will continue to investigate the characteristics of indoor radio propagation at 2GHz to 20GHz and higher frequencies.

### ACKNOWLEDGEMENTS

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