Davies, R. L., Bensebti, M., Beach, M. A., & McGeehan, J. P. (1991). Wireless propagation measurements in indoor multipath environments at 1.7 GHz and 60 GHz for small cell systems. 589 - 593. 10.1109/VETEC.1991.140560

Wireless Propagation Measurements in Indoor Multipath Environments at 1.7GHz and 60GHz For Small Cell Systems.

R.Davies, M.Bensebti, M.A.Beach, J.P.McGeehan.

Centre for Communications Research,
University of Bristol, UK.

Abstract.

Given the current interest being shown in the utilisation of the frequency bands around 1.7/1.8GHz and 60GHz, work has been undertaken at Bristol in determining channel characteristics in these two ranges. This paper describes wideband measurements which have been conducted in a variety of indoor locations in and around Bristol University. RMS Delay spreads were calculated, and used to compare levels of multipath activity at the two frequencies. The levels of multipath measured at the two frequencies can be related to the size of the rooms involved, and the measurement techniques. Any differences due to atmospheric absorption at 60GHz, were found to be negligible.

1. Introduction.

Channel characterisation has always been an important part in the development of new wireless communications systems. As the system specifications become more complicated and the spectrum utilisation increases, a knowledge of the types of errors that the channel could introduce is of vital importance for acceptable operation. Both the European RACE and COST 231 projects are concerned with providing broadband services over comprehensive coverage areas and have identified the frequency bands around 1.7/1.8GHz and 60GHz as possible carriers.

Concern exists over the performance of mobile services in the highly attenuative and multipath environment that exist within buildings. As this is likely to be the location with the highest user-density, it is important to understand the types of propagation mechanisms which occur. To this end, work has been undertaken at the Centre for Communications Research within Bristol University to look at specifically the wideband propagation effects that may be encountered in office and laboratory environments in the one cell per room scenario.

2. Channel Sounding Equipment.

The two channel sounders used for these indoor measurements have both been described in some detail in past publications [1,2], so it will suffice to say here that although the 60GHz sounder was a Cox-type PRBS correlation receiver [3] and the 1.7GHz sounder was of the pulsed transmission type, they both performed equivalently in terms of their pulse width and echo path resolution. The 60GHz system used biphase modulation of a 2047 bit maximal length sequence running at 100Mbit/s which was transmitted at an average power of 25mW. The 1.7GHz system transmitted 20ns pulses at an interval of over 2μs and a peak power of 20mW. Both systems had an echo resolution of 10ns or 3 metres.

The area where the two systems differed significantly was in the antennae used. The 1.7GHz sounder always used vertically polarised half-wave dipoles for both the transmitter and receiver. The 60GHz system used a 20dB horn at the transmitter and either a 20dB horn or an omnidirectional antenna at the receiver.

3. Wideband Channel Model.

The wideband multipath channel is often modelled as a time varying linear filter with complex impulse response [4]:

$$h(t,\tau)=\sum_{i} A_{i}(t,\tau)\exp(j\phi_{i}(t,\tau))\delta(\tau-\tau_{i}(t)) \qquad (1)$$

For the indoor propagation environment where the time varying factors of the impulse response typically are human movement, it is appropriate to treat the channel as quasi-stationary [4]. This allows multiple measurements to be taken with the knowledge that the non-noise parts of the impulse response will be acceptably constant.

It is usual to assume that the phase variations in the complex impulse response have a uniform distribution [4] and so only the amplitude and delay components are considered here. The starting point for most calculations on wideband multipath propagation is the power delay profile as this is the format in which the impulse response emerges from typical wideband mesurement equipment. The power delay profile can be expressed as:

$$P(\tau) = \sum_{i} A_{i}^{2}\,\delta(\tau-\tau_{i}) \qquad (2)$$

There are many measures of multipath activity in the wideband channel but the most suitable in this instance is the RMS Delay Spread. The RMS delay spread has the combined advantages of being easy to compute and, also is widely ued by other works in the field thus enabling comparisons to be madewith other results. The RMS delay spread can be defined from the moments of the power delay profile:

$$M_0 = \sum_i P(\tau) \qquad (3)$$

$$M_1 = \sum_i \tau_i P(\tau) \qquad (4)$$

$$M_2 = \sum_i \tau_i^2 P(\tau) \qquad (5)$$

$$(\text{RMS Delay Spread})^2 = \frac{M_2}{M_0} - \left[\frac{M_1}{M_0}\right]^2 \qquad (6)$$

Using correlation techniques to extract the power delay profile as with the 60GHz sounder, introduces correlation noise to the output which has been shown to introduce errors in RMS Delay spread calculations [2]. For this reason, a noise threshold was introduced into the computations, below which, all data were assumed to be zero.

4. Propagation Experiments.

Three areas within the Faculty of Engineering at Bristol University were chosen for the wideband propagation measurements. Area (a) was the Communications Research Laboratory. This is essentially and open plan site consisting of three rooms of roughly the same dimensions. The rooms are all about 10 metres square and join to form an 'L' shape. Two of the rooms were used for the propagation trials. Area (b) was a standard corridor of dimensions 3 metres by 30 metres with doors leading from one side of it. Area (c) was the main teaching laboratory (15x30m) in the Faculty, and as such is a fairly large room with regularly spaced benching. For all the experiments the receivers remained stationary, while the transmitters moved over a regularly spaced grid which covered the available floor space as completely as possible. For the 1.7GHz system, each recorded power delay profile was the average of 64 captured profiles, whereas the 60GHz PRBS sounder has in-built averaging due to the offset of the two sequences in the receiver. Here each recorded power delay profile is the average of 25000 full profiles.

5. Results.

One of the attractive features of 60GHz for radio communications is that it coincides with a peak in atmospheric oxygen absorption. This gives an extra attenuation of 15dB/Km above the free space path loss. The power received from distant reflectors can be reduced considerably thus lowering the associated RMS delay spreads. Figures 1a and 1b show typical examples of received indoor power delay profiles at 1.7GHz. It is interesting to note that most of the multipath components occur within a 200ns delay window. This corresponds to an excess path length of 60 metres. The atmospheric attenuation therefore, will be in the order of only a few dBs for the maximum path lengths and so the effect is reduced considerably and ceases to be the dominant factor in the 60GHz propagation mechanism.

Figures 2,3 and 4 show the cumulative distributions of RMS delay spreads for the areas a, b and c described earlier. For area a, the Communications Laboratory, the median and maximum values of delay spread were 22ns and 47ns at 1.7GHz, and 6ns and 14ns at 60GHz. For area b, the corridor, the values were 8ns and 20ns at 1.7GHz, and 3ns and 13ns at 60GHz. For area c, the Teaching Laboratory, the values were 24ns and 43ns at 1.7GHz, and 13ns and 35ns at 60GHz.

It is obvious from the three graphs that there is some considerable difference between the RMS delay spread values measured at the two different frequencies and between the values measured in different locations. The differences due to frequency can be put down to four factors after ruling out oxygen absorption:

i) Figure 5 shows the variation in reflection coefficient for different angles of incidence and for frequencies ranging from 1MHz to 100MHz. Although this is not the frequency range of interest, it does show that the reflection coefficient varies. What it does not show is that the electrical parameters (conductivity and permittivity) also vary with frequency. This area has not received much attention to date, and publications that are available are from the field of microwave heating, so tend to deal with foodstuffs and human tissue rather than building materials and only go up to around 10GHz [5,6].

ii) Blocking of radio signals by building materials at 60GHz is a very significant factor in indoor propagation [7]. The difference in attenuation from 1.7GHz to 60GHz can contribute by reducing echoes that might be received from reflectors outside the room. For the building in question, extensive narrowband measurements were conducted to determine the attenuation of the walls at the two frequencies. Due to the construction techniques used (thick reinforced concrete), the walls are virtually impenetrable by radio waves at these two frequencies and so the differences between the two frequencies are negligible.

iii) The main cause for the lower delay spreads at 60GHz in this case is the types of antennae used. The half-wave dipoles used in the 1.7GHz system were vertically polarised , and as such have an omnidirectional pattern in azimuth whereas the 20dB horns used in the 60GHz system have a much narrower beamwidth. This means that the 60GHz system will receive far fewer multipath components, and none from behind the receiver. It is yet to be seen how much of a factor this is, but it could explain completely the differences in the values of RMS delay spread.

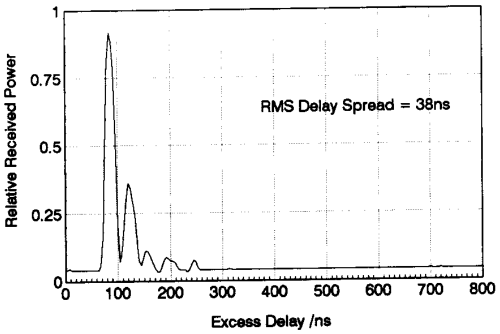

Figure 1a. Sample Power Delay Profile

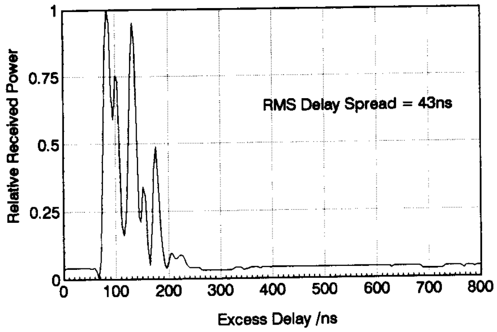

Figure 1b. Sample Power Delay Profile

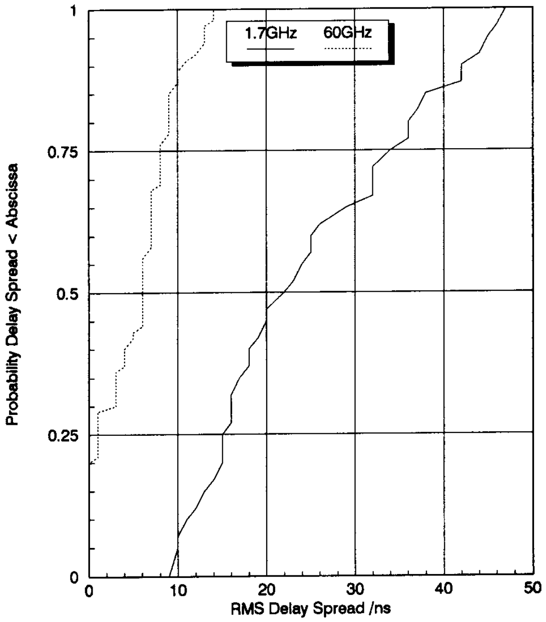

Figure 2. RMS Delay Spreads for Area (a).

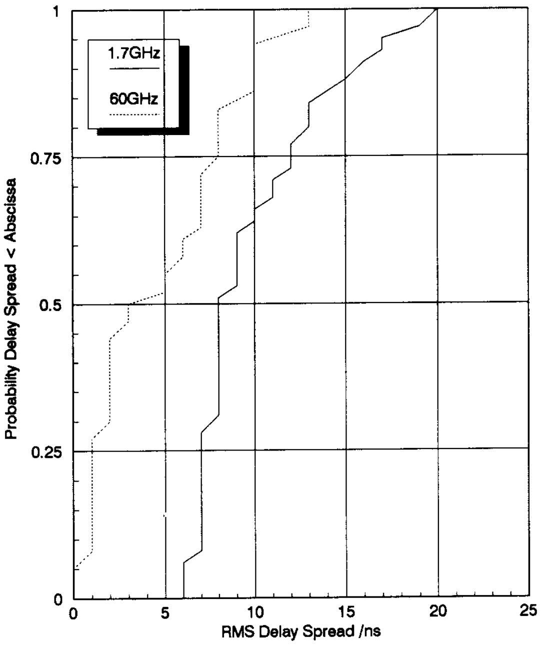

Figure 3. RMS Delay Spreads for Area (b).

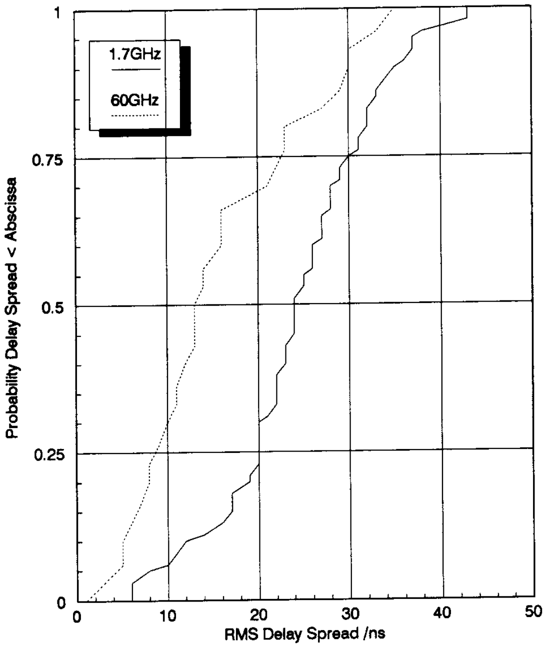

Figure 4. RMS Delay Spreads for Area (c).

iv) It can be seen from figure 2. that the results for area a vary to a greater extent than they do for the other areas. The reason for this is that the 1.7GHz measurements were performed while the room in question was undergoing refurbishment and so was empty whereas the 60GHz measurements were taken at a later time when the refurbishment was complete. The effect of the furnishings can be looked at in two ways. Firstly, objects in the room can be sources for extra reflections, but these new echoes are likely to be within a time window defined by the dimensions of the room and so will have little effect on the measured RMS delay spreads. The other point is that the extra objects can act as barriers to existing echo paths. In this instance the second point is dominant and has the effect of reducing the RMS delay spreads measured at 60GHz.

The other important factor in the range of RMS delay spread values is the size of the rooms used for the measurements. It has been assumed that the attenuation due to building materials is large enough here to effectively restrict any reflections contributing in the power delay profiles to the room under test. This assumption explains why the results for the three different areas vary to some extent. The size of the rooms in this building determine the types of delay spread values that are likely to be received. This also applies to indoor measurements that have been reported in literature, the larger values reported are for areas which are much larger than the ones that were measured here [8,9].

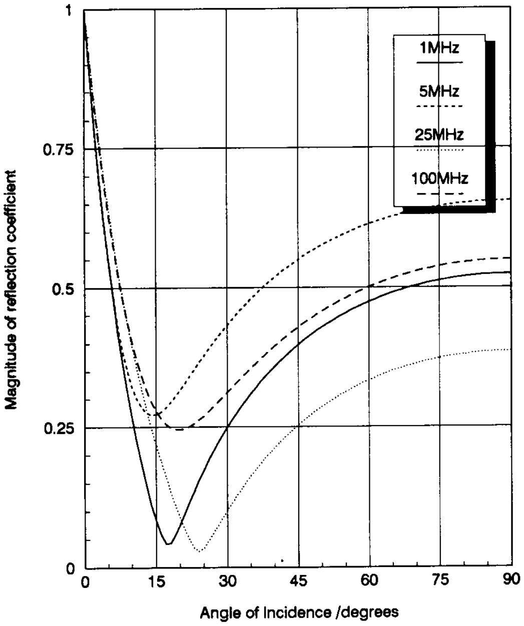

Figure 5. Reflection Coefficients for Different Frequencies.

6. Conclusions.

Wideband propagation measurements were performed within the Faculty of Engineering Building at Bristol University at 1.7GHz and 60GHz. The purpose of the trials was to investigate the type of RMS delay spread that would be encountered in this building, and also to see whether there was any significant difference between the results obtained at the two frequencies. The measured data gave RMS delay spreads which were always below 50ns at 1.7GHz and always below 40ns at 60GHz. The differences in values for one frequency can be explained by the dimensions of the rooms in question, and the knowledge that attenuation through the walls of the building is of the order of 15dB. This attenuation effectively restricts received multipath components to reflectors within the room in question. An important consequence of this is that the excess path lengths on received echoes are short so that atmospheric oxygen absorption at 60GHz is not an important effect.

The differences in the results between the two frequencies can be attributed to building material attenuation, differences in furnishings, frequency dependence of reflection coefficients and differences in antennae used.

The level to which these delay spreads restrict transmitted data rates can be determined from the normalised delay spread. This is defined as the RMS delay spread multiplied by the transmitted bit rate. It has been shown in simulations [10] that simple switched antennae diversity is effective up to normalised delay spreads of 0.2. This gives a bit rate of 4Mbit/s, above which, more complicated diversity techniques would be needed to keep error rates to acceptable levels.

From these measurements, indoor wideband propagation at 1.7GHz did not vary to any extent from that at 60GHz so they are as suitable as each other for indoor usage. The only advantage that 60GHz has over 1.7GHz is the amount of available bandwidth.

7. Acknowledgement.

Funding for this work was provided by SERC UK and Thorn EMI and the authors would like to express their thanks to these two organisations.

8. References.

[1] R.Davies, A.Simpson, J.P.McGeehan, 'Propagation Measurements at 1.7GHz for Microcellular Urban Communications', Electronics letters Vol.26, No.14, 5th July 1990, pp.1053-1054

[2] R.Davies, M.Bensebti, M.A.Beach, J.P.McGeehan, D.C.Rickard, 'Channel Sound Measurements at 60GHz Using Wideband Techniques with Particular Reference to Microcellular Personal Communications', 5th IEE Int.Conf. on Mobile Radio & Personal Communications, Warwick University, U.K. December, 1989.

[3] D.C.Cox, 'Delay Doppler Characteristics of Multipath Propagation at 910MHz in a Suburban Mobile Radio Environment', IEEE Trans. Ant. and Prop. Vol AP-20 No.5 September 1972. pp.625-635

[4] S.W.Wales, D.C.Rickard, M.A.Beach, R.Davies, 'Measurement and Modelling of Short Range Broadband Millimetric Mobile Communication Channels', IEE Colloquium on Radiocommunications in the Range 30-60GHz, 17 Jan 1991. pp.12/1-12/6

[5] A.C.Metaxas, R.J.Meredith, 'Industrial Microwave Heating', IEE Power Engineering Series 4. 1988. pp.28-31

[6] D.M.Sullivan, D.A.Borup, O.M.Gandhi, 'Use of the Finite-Difference Time-Domain Method in Calculating EM Absorption in Human Tissues', IEEE Trans. on Biomedical Eng. Vol.BME-34, No.2, Feb.1987. pp.148-157

[7] A.R.Tharek, 'Propagation and Bit Error Rate Measurements in the Millimetre Wave Band about 60GHz', PhD Thesis, University of Bristol, U.K. 1988. pp.69-90

[8] D.M.J.Devasirvatham, M.J.Krain, D.A.Rappaport, C.Banerjee, 'Radio Propagation Measurements at 850MHz, 1.7GHz and 4GHz Inside Two Dissimilar Office Buildings', Electronic Letters, Vol.26, No.7, 29th March 1990. pp.445-447

[9] K.Pahlavan, R.Ganesh, T.Hotaling, ' Multipath Propagation Measurements on Manufacturing Floors at 910MHz', Electronics Letters, Vol. 25, No.3, 1989. pp.225-227

[10] A.R.Nix, J.P.McGeehan, 'Modelling and Simulation of Frequency Selective Fading Using Switched Antenna Diversity', Electronics Letters Vol.26, No.22, 25th October 1990. pp.1868-1869