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Comparison of Delay Spread Measurements with Ray Tracing Simulations at 1890 MHz

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Introduction

A wideband channel sounder is used to measure the complex impulse response of the radio channel, using a swept time delay cross correlator method. The sounder uses a chipping rate of 100 MHz, and has a resolution of 10 nS, equivalent to a path length difference of 3 metres. Omnidirectional vertically polarised antennas are used for both the transmitter and receiver. Indoor measurements are made in the Engineering School building, which has a mixture of small offices, and large open plan lab spaces, together with long corridors. Outdoor measurements are done within the campus, a compact collection of buildings of irregular shape. Ray tracing simulations are performed for the same environments using the personal computer-based Microcell Communication Simulator (MCS), marketed by EDX Engineering, Inc., Oregon, USA. This simulator makes a number of simplifying assumptions, such as working only in two dimensions, and only allowing a one wall transmission per ray. Simplifying assumptions must also be made for the dielectric properties of the wall building materials. This paper compares simulated delay spreads with the measured values, in a variety of locations. An indoor measurement was done for a single receiver location within a large lecture room, with the transmitter in a nearby corridor. A series of indoor measurements was also done with the transmitter in a single location in a side corridor and the receiver moving along a route following a main corridor. Most of this route was non-line-of-sight, apart from one section as the side corridor was passed. Outdoor measurements were done on the university campus in a large courtyard-like area, completely surrounded by irregular shaped buildings, and complicated by the three dimensional factors of sloping ground levels, and various elevated pedestrian bridges, which could not be included in the two dimensional ray tracing database. Measured RMS delay spreads were generally larger than the raytracing predicted values, by up to 90 nS, except for outdoor situations of simple building geometry, where agreement over most of the route was good, within +/- 10 nS.

Ray Tracing

The EDX Engineering Inc. MCS software uses point to point ray tracing techniques to identify the multipath propagation arriving at the receiver. This idealised approach results in infinite impulse resolution, corresponding to unlimited system bandwidth. Multiple generation wall reflections, up to ten, and up to two corner diffractions, may be included, together with diffuse wall scattering if desired. For fixed transmitter and receiver locations, plots of the channel impulse response and angle of arrival are generated, and the RMS delay spread is calculated. If a route along which the receiver moves is specified, a plot of RMS delay spread verses distance along the route is produced, for up to 200 fixed positions on the route. Grid study plots can also be done. The software has other features described in the user manual.

Limitations

Some limitations arise from the software, and from unavoidable simplification of the database information. The version of MCS used (Version 1.0) works essentially in 2 dimensions, apart from including one ground reflection. Terrain height variation is not included, and in the case of indoor applications, ceiling effects are not considered. Only one wall transmission of a ray is included, and this path is not onward propagated, that is it may not be further reflected or diffracted after passing through a wall.

The database describing the environment is a text file made up of coordinates locating each building corner, an angle indicating the direction the corner faces, and a category for each wall section describing the electrical properties of the building material used. Buildings, or internal walls and partitions, are thus described in two dimensional plan form as outlines. The number of wall sections and corners must not exceed 500 within the cell radius, which can be chosen as either 500 or 1000 metres. So the complexity and detail of buildings is reduced to an over-simplified two dimensional outline. For the indoor case, walls are treated as infinitely high with no ceiling. Items such as steel fluorescent light units, which may be strong reflectors, cannot be included, and detail such as furniture, although many wavelengths in size, is not included in this study.

The electrical properties (permittivity and conductivity) used for the building wall materials are, at best, an approximate estimate. Windows within walls are difficult to include, except by the token gesture of modifying the average electrical parameters. In the case of internal partition walls, the electrical parameters are also in doubt, especially where the wall construction is non-homogeneous, such as with steel framework plasterboard walls.

Wall Types and Estimated Electrical Properties

The estimates below are based on anechoic chamber measurements done at Bristol University, and from results in Ref. 1.

Wall type Number	Description
1	reinforced concrete, half height windows
2	solid reinforced concrete
3	plasterboard and steel frame
4	plasterboard and timber frame
5	metal
6	timber door

Wall type	Conductivity (Siemens)	Relative Permittivity	Surface Roughness (metre)	Thickness (metre)	Wall Attenuation (dB)
1	5E-4	3	2E-3	0.3	6
2	5E-3	2.7	2E-3	0.3	12
3	5E-2	3	1E-3	0.1	4
4	5E-3	2.7	1E-3	0.1	2
5	9E6	1	0	0.1	100
6	3E-4	2	1E-3	0.03	1

Channel Sounder

The sliding correlator channel sounder measures the complex impulse response of the radio channel (Ref. 2,3,4), and uses a PN sequence of length 1023 and chip rate 100 MHz, an RF bandwidth of 200 MHz and a centre frequency of 1890 MHz. The sliding correlation time scale factor is 20,000.

Back to Back Tests

Laboratory back-to-back tests were done to investigate the linearity, dynamic range and resolution of the Channel Sounder (Figure 1). In these tests, the transmitter and receiver are connected via coaxial cable, fixed and variable attenuators, and an artificial channel which splits the signal into three paths, delaying the second path by 50 nS and the third path by 100 nS relative to the main path. Compared with the main path, the second path has an additional loss of 4.5dB and the third path an additional loss of 8.5dB.

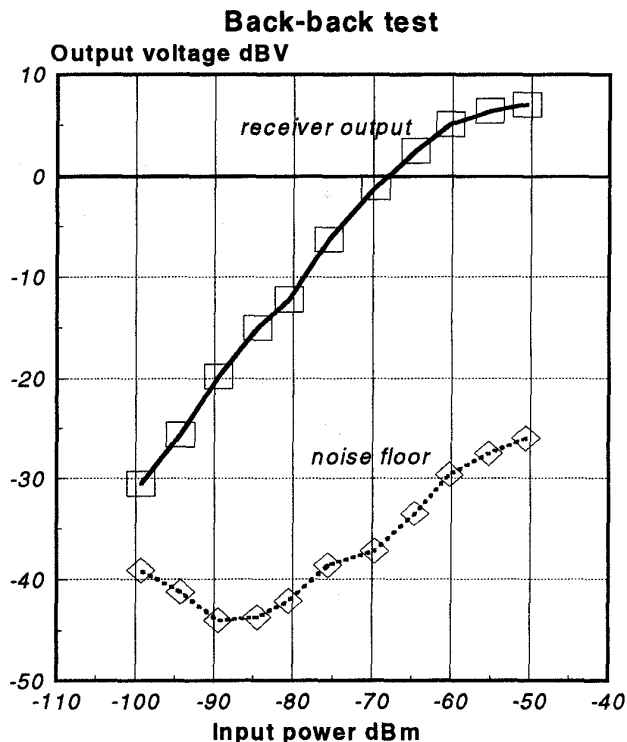


FIGURE 1

The Channel Sounder receiver polar output voltage is linear for RF input levels of <-100 dBm to -60 dBm, and for input levels between -90 dBm and -60 dBm the dynamic range between the output level and the approximate noise floor is >25 dB. See Figure 1.

Resolution of the artificial channel paths is shown in Figure 2, with the second and third paths delayed 50 nS and 100 nS respectively, and with the expected relative amplitudes. Each peak has a -3 dB width of 10 nS, confirming the expected resolution. Small spurs on the skirts of the peaks are probably caused by reflections in the approximately 5 metre cable used for back-to-back testing.

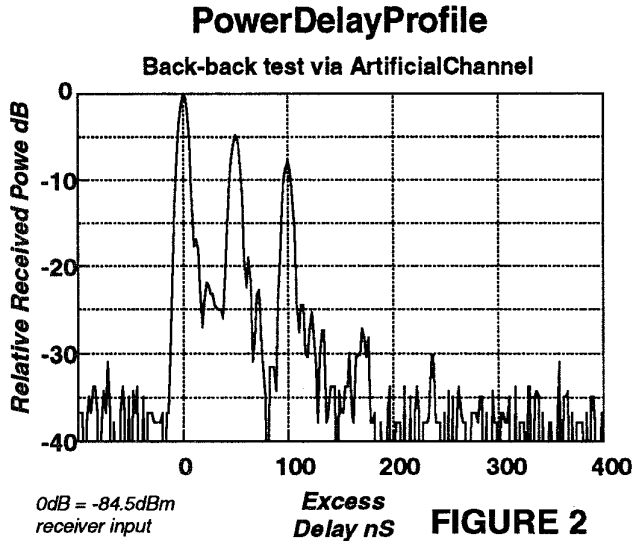
Channel Sounder Accuracy

Amplitude accuracy is within +/- 1.5 dB over the whole dynamic range, based on back-back linearity tests. Timing accuracy is precise, locked to a rubidium oscillator.

Measurement Method

The battery powered transmitter is mounted on a small trolley, with the discone antenna mounted 1.8 metre above ground level. The receiver is also battery powered and trolley

mounted with 1.8 metre antenna height. Data is collected using a portable notebook computer. Transmitter output power is adjusted to keep the receiver input power within a favourable range at each measurement point. At each measurement point, between 3 and 6 measurements are taken, moving the receiver trolley randomly within a radius of approximately 5 wavelengths from the initial position. Measurements were done on Sunday evening, when the campus and building concerned were almost deserted, avoiding effects from pedestrians or vehicles.



RMS Delay Spread

A threshold of 15dB below the main peak is used (Ref 5). All components below this threshold are set to zero. A range threshold is also used, with all signals arriving more than 1 microsecond after the main peak being disregarded. Calculation of the delay spread is corrected for the finite but small width of the channel sounder impulse response.

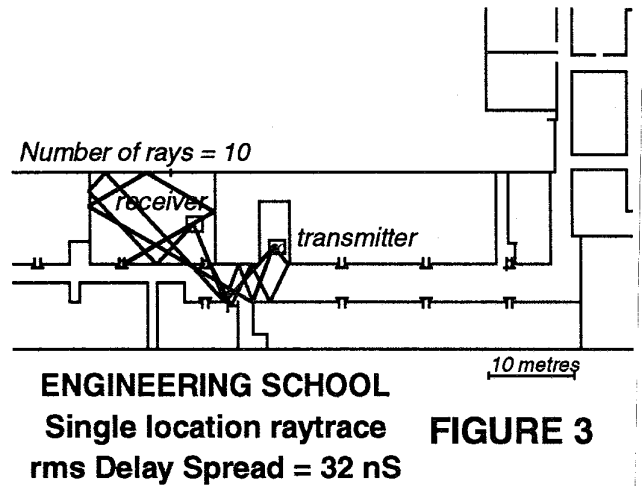
Indoor Measurements

Indoor measurements were done on Level 7 of the Engineering School. This is an L shaped building, with a central corridor of approximately 70 metres along the longer leg. Side passages, large lecture rooms and labs, and small offices open off the main corridor. The floor is reinforced concrete. A suspended plaster ceiling with a light steel frame is at 2.4 metre height above floor level. Reinforced concrete pillars are distributed throughout the floor. Partition walls are a mixture of concrete, plaster on a timber frame, and plaster with a steel frame, with various styles of internal windows, typically in the upper one third of the walls. Doors are of timber. In the raytracing plan, with the exception of doorways into some of the lecture rooms, only the corridor outlines are included because rays with more than one wall transmission are disregarded.

Single Point Measurement

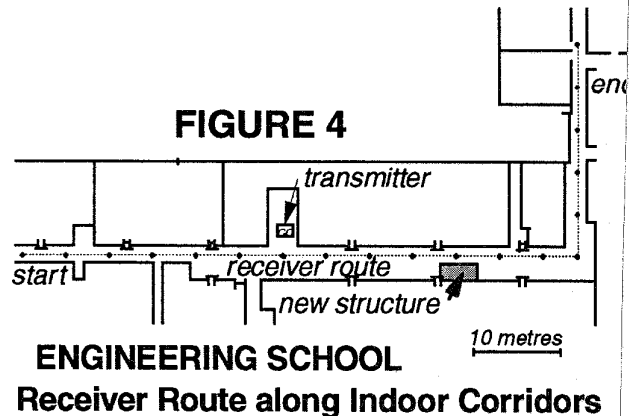
For both the single point and route measurements, the transmitter is located in a wide side corridor, opposite steel lift doors.

Measurements were made at a single location in a lecture theatre, with the receiver moved randomly between each of 9 measurements within a 5 wavelength radius of the initial point. RMS Delay Spread values varied between 21 and 33 nS, with an average value of 26 nS and standard deviation of 4 nS. The raytracing plot for this situation is shown in Figure 3, and gave a delay spread of 32 nS, 23% or 6 nS greater than the average measured value of 26 nS.

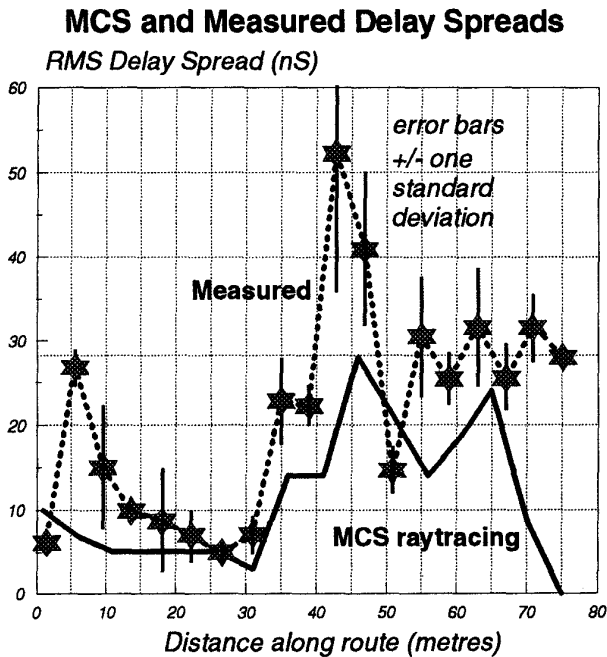


Route Measurement

The receiver route, up the corridor past the transmitter, and then turning left into a right angle corridor, is shown in Figure 4. Measurements were made every 4 metres, with between 3 and 5 measurements around each point. Figure 5 compares measured results with raytracing results. Generally the measured delay spreads are greater than the raytraced values, by up to 30 nS. Part of the reason for this may be that a new structure, not included in the ray tracing database, jut into the corridor. Ceiling reflections, and reflections from steel lockers and other furniture not accounted for in



raytracing would also be expected to increase delay spread values. Note that soon after the corner is turned in the corridor, the raytrace simulation signal vanishes.



ENGINEERING SCHOOL Indoor Corridor Route **FIGURE 5**

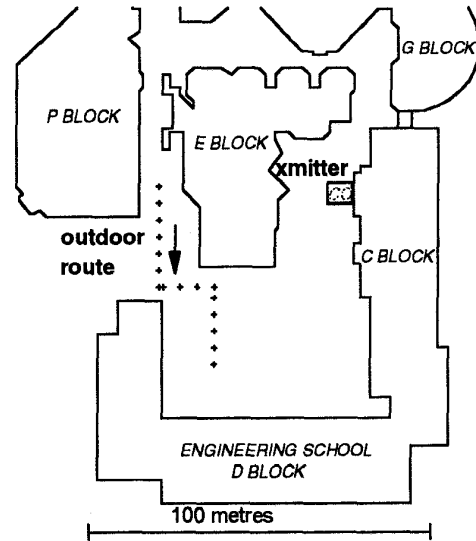
Outdoor Measurements

The receiver route is shown in Figure 6, and Figure 7 compares measured delay spreads with raytrace values. In most cases 4 measurements were made around each point. Over the first 20 metres of the route, agreement is poor, with measured delay spreads being up to 90 nS greater than the raytrace values. From 20 metres to 70 metres, the curves approximately follow the same shape with delay spread agreement within 15 nS, apart from the region around 50 metres, where the discrepancy reaches 35 nS.

Some significant reinforced concrete elevated pedestrian walkways and supporting pillars were omitted from the raytrace database. Apart from the pillars, the 2 dimensional raytracing software cannot cope with the elevated structures. The under surface of these is between 4 and 5 metres above ground level. At the start of the route, ground altitude is about 3 metres below ground level at the transmitter, and the level gradually rises along the route. The early part of the route is most influenced by the elevated walkways and lower ground level, probably contributing to the greater measured delays. Towards the end of the route, on more level ground and with a line-of-sight component, agreement with raytracing results is good, within 5 nS.

Figure 8 shows the location of the elevated walkways.

Figure 9 shows a measured power delay profile for the start of the route where delay spreads are much larger than raytrace values, and Figure 10 shows a profile at the end of the route, where agreement becomes good.



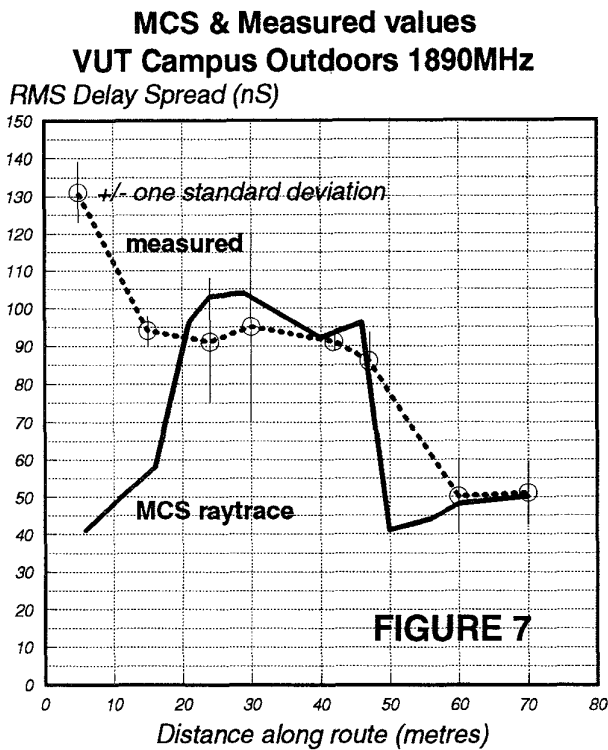
Footscray Campus Outdoor Route of Receiver **FIGURE 6**

Conclusions

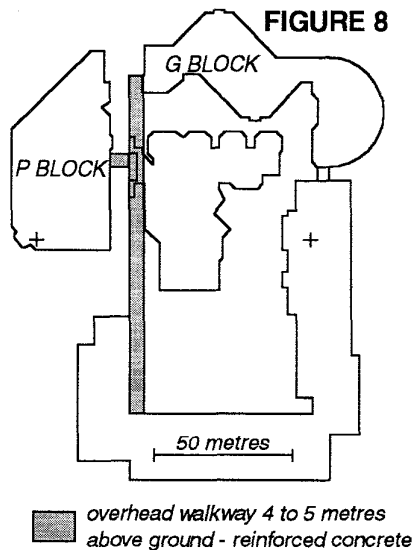
In view of the uncertainty in the estimates used for building material electrical properties, simplifications and omissions made with raytracing plans, and the 2 dimensional limitation of the raytracing software, it is perhaps surprising that the raytracing simulations produce useful estimates of delay spreads over most of the routes tested. The raytracing program is not really aimed at indoor use. In outdoor use, if the building geometry is simple with vertical walls and a plan representable in 2 dimensions, the raytracing simulations can produce accurate predictions of delay spread.

Acknowledgements

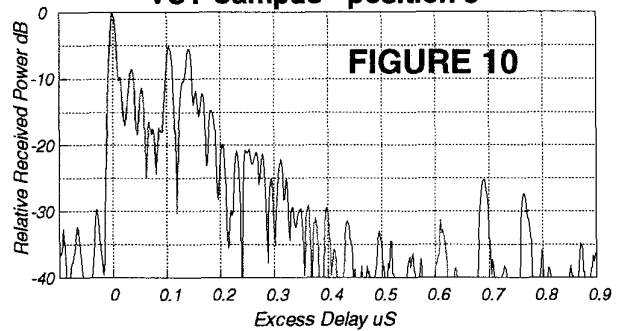
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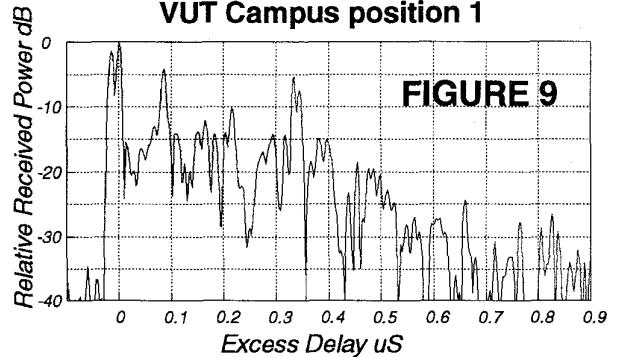
Footscray Campus
Showing overhead walkways
FIGURE 8



Power Delay Profile - rms delay spread 61nS
VUT Campus - position 8



Power Delay Profile
rms delay spread 126nS
VUT Campus position 1



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