# Modelling Inter-Floor Radio-Wave Propagation in Office Buildings

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## Abstract

*A 2D model of an office building has been analysed at 1.0GHz using the FDTD method. Results indicate inter-floor radio-wave propagation is supported by two distinct mechanisms: direct penetration and floor-edge diffraction. The power of the direct component decreases linearly by 10-15dB/floor penetrated, whereas the diffracted component is significantly smaller and asymptotes toward a constant value. The presence of floor-edge diffraction is a noteworthy finding, as it provides a physical basis for previously reported, but hitherto, unexplained, results.*

## I. Introduction

The ubiquitous growth in wireless communication services has led to increased levels of radio frequency interference. Indoor wireless systems are particularly susceptible to this, as all transmitters and receivers are usually in close physical proximity. As interference adversely affects system capacity and reliability, there is a need for 'good' models to predict signal strengths (and, therefore, levels of interference) inside buildings. 'Good' prediction models are accurate, easily generalised for any building, and relatively simple. Currently, empirical models based on experimental data are popular [1], but these require many measurements, can be site specific, do not explain the physical phenomena observed, and thus cannot be easily generalised.

Indoor environments can be very complex, and a more thorough understanding of radio wave propagation can be gained through an electromagnetic approach [2]. However, fully electromagnetic models are inappropriate for day-to-day use, due to complexity and the requirement for detailed knowledge of the physical geometry and layout. Therefore, we are developing *mechanistic* models that retain the accuracy of their electromagnetic foundations, but are appropriate for system planning. The mechanistic models are derived via a rigorous investigation of indoor environments using the Finite-Difference Time-Domain (FDTD) method. Because of computational requirements only 2D problems have been examined to date.

This paper examines propagation between floors in office buildings, an important consideration for interference. While the problem of interfering transmitters on the same floor has been examined previously [3], the propagation mechanisms that support inter-floor interference are not as well understood.

## II. FDTD Modelling

To isolate the mechanisms influencing inter-floor propagation, a simplified 2D geometry is being considered. This geometry considers a vertical 'slice' through the building, consisting of eight dielectric slabs (representing concrete floors) in free space, and is shown in Fig. 1(a) Other building features such as windows, the central services core (lifts and stairways), internal partitions, and concrete reinforcing are not considered in

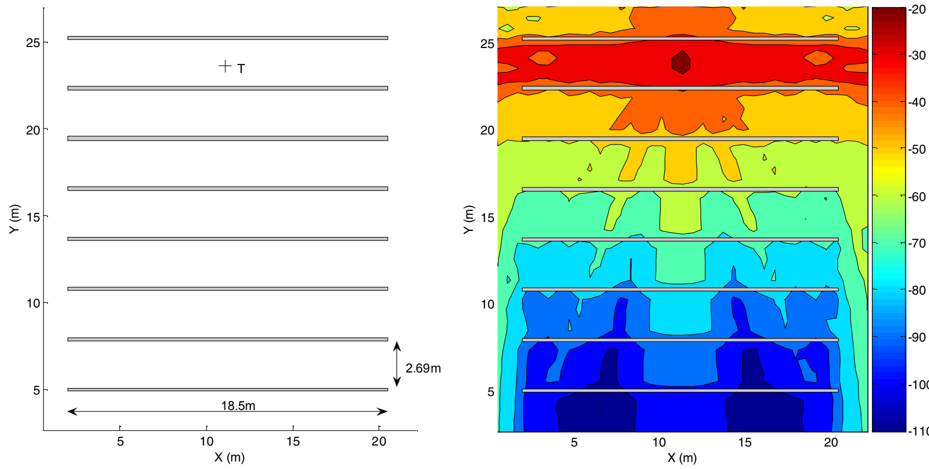


Fig. 1 (a) 2D floor geometry. (b) Contour plot of received power (in dBm).

this paper, but are the subjects of an ongoing investigation. Specific dimensions for the geometry are chosen to match the School of Engineering office tower at the University of Auckland—a typical 1960's reinforced concrete structure. This choice will allow meaningful comparisons between FDTD results and a planned measurement study.

Each concrete floor is 18.5m long, 0.20m thick and is modelled as a solid dielectric slab with relative permittivity of 4.0. The floor-ceiling height is 2.69m. The simulation space is 22.5m × 27.5m, and the area outside the building is surrounded by a uniaxial perfectly matched layer (UPML). A single, horizontally polarized, electric field component is used to excite the $TM_z$ lattice at a frequency of 1.0GHz—and is located on the top floor of the building at 'T' in Fig. 1(a) Numerical dispersion is minimised by ensuring the lattice density is at least 15 cells/λ [4]. The electric field amplitude and phase are measured when the time domain excitation reaches steady-state.

## III. FDTD Results

Small scale fading, caused by multipath, is removed by averaging signals over 2λ × 2λ sectors. 120 sectors are taken across each floor and the distance from the centre of each sector to the transmitting antenna is calculated. Fig. 1(b) shows a contour plot of the received power (in dBm) across each floor. Attenuation is seen to increase with distance from the transmitter and the number of floors penetrated. The variation in power across a floor is observed to be up to 15dB, as multiple reflections give rise to complex amplitude fluctuations that can extend over several sectors. The specific pattern was found to be significantly dependent on the floor thickness. Scatter plots of path loss versus the transmitter-receiver (T-R) separation for 0.10m and 0.30m floor thickness are shown in Fig. 2(a) It is noted that thicker floors experience more attenuation, leading to lower received power and higher path loss overall. As more floors are penetrated, the attenuation introduced by each additional floor decreases.

These results suggest a simple distance-dependency model, similar to that proposed by Seidel [1], can be used to predict average sector power. The received power at a T-R separation of $d$ (m) is given by

$$P_r(d)\ [\text{dBm}] = P(d_0) - 10n\log_{10}\left(\frac{d}{d_0}\right) - F$$

where $P(d_0)$ is the power at a distance $d_0$ (m) from the transmitter, $n$ is the distance-dependency exponent, and $F$ represents the increased propagation loss between floors. Results indicate a distance dependency exponent of 1.0 (i.e. 2D 'free space') is appropriate.

## IV. Propagation to Other Floors

The results from the FDTD investigation indicate that two propagation 'paths' are possible: 1) transmission through the floors; and 2) transmission via paths external to the building. Transmission through the floors includes the direct and multiple-reflection paths, and is entirely contained within the building perimeter. In the geometry considered, diffraction around the floors is the only external path possible. Energy from diffracted paths is observed to travel down the outside face of the building, and can re-enter at another floor. This mechanism could be influenced by external features, such as ledges and inset windows. A further investigation is currently underway to confirm if these features (which make the external face electromagnetically rough) can act as wave-guiding structures. The presence of external diffraction-based mechanisms that can propagate significant levels of power to other floors is a significant finding, as it provides a deterministic, physical basis for, hitherto unexplained, behaviours reported in [1].

The power of the direct component decreases with increasing T-R separation and by floor attenuation. Received power will decrease by a fixed amount per floor, depending on thickness and concrete conductivity. For typical concrete conductivity (0.05 S/m) [5] this is between 10-15dB. Therefore, the power (in dBm) of the direct component decreases rapidly, but linearly with the number of floors penetrated. By contrast, the power of the diffracted component will be significantly lower, but relatively constant with distance and independent of the number of floors.

With the FDTD model it is possible to isolate both internal and external propagation mechanisms. For example, extending the floors into the absorbing boundary prevents diffraction, or indeed any other external mechanism. In this case results show that the path loss increases linearly with the number of floors penetrated. Conversely, the diffracted component is isolated by placing a metal screen in the centre of the floor beneath the transmitter, eliminating the direct component. In this case any fields observed must be solely due to external diffraction paths. Fig. 2(b) shows the path loss for both

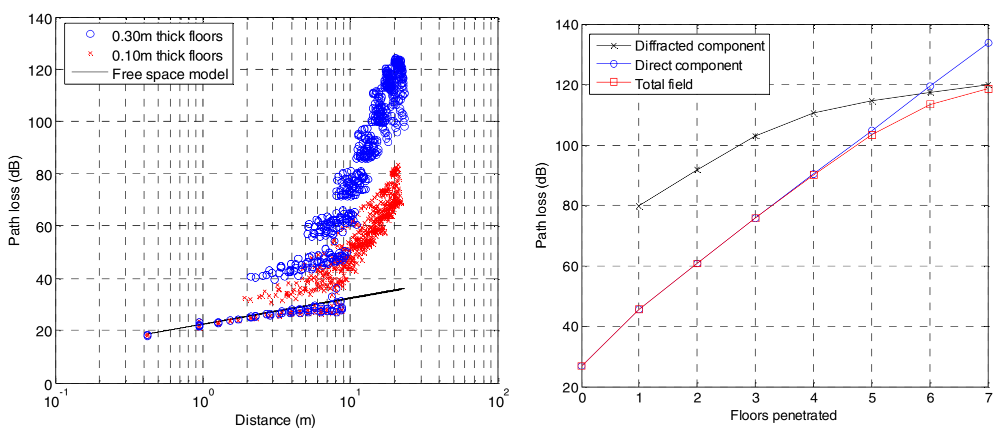


Fig. 2 (a) Path loss for 0.10m and 0.30 thick floors; (b) Average floor attenuation for direct and diffracted components.

components. The diffracted component has high path loss, and increases at a much slower rate with the number of floors penetrated. The combined effect causes path loss to increase linearly—until the power of the diffracted component is approximately the same as the direct (-90dBm in this case)—at which point the rate of increase in path loss slows, and is dominated by the diffracted component.

This finding compares well with previously published measurements taken in several office buildings [1, 6, 7]. Diffraction around the floors has been modelled with ray-optics and the uniform theory of diffraction (UTD) [7]. However, this only considered diffraction at a single floor, modelled as an absorbing wedge. For the model considered in this paper, multiple, co-linear diffracting screens may be more appropriate. However, the UTD is known to fail in this scenario [8]. As the FDTD is a full-wave method, more reliable results can be expected.

## V. Conclusions

A model of an office building, consisting of multiple, lossy dielectric floors, has been analysed at 1.0GHz using the FDTD method. Results show two propagation mechanisms are present—direct transmission and diffraction around the floors. The power of the direct component decreases linearly with the number of floors penetrated. The attenuation introduced by each floor depends on the concrete conductivity and thickness. The floor diffracted component has a power of approximately -90dBm and does not influence results until the direct component has been sufficiently attenuated. This is a significant finding and will aid in the development of mechanistic models for radio wave propagation inside buildings. Future work will include validation through measurements, analysis of more complex geometries and the effect of rotating the field polarization.

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