Measurement of building transmission loss using wideband radio channel sounding

Citation for published version (APA):

DOI:
10.1049/el:20000746

Document status and date:
Published: 01/01/2000

Document Version:
Publisher’s PDF, also known as Version of Record (includes final page, issue and volume numbers)

Please check the document version of this publication:
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In summary, the receiver algorithm operates directly on the base-band samples \( g(n) \). After phase correction, the error signal required for the optimisation of the receiver parameters is constructed as follows:

\[
e(n) = d(n) - y(r) = d(n) - e^T(n)\hat{e}(n) \tag{7}
\]

In the training mode the desired signal \( d(n) \) is precisely known. In contrast, in the decision-directed mode it is constructed from \( J+1 \) by hard limiting. The tap gains of the FF and FB equalisers are adapted by using eqn. 5. The phase error measure is estimated by employing eqn. 7 and is subsequently fed into the linear predictor in order to predict future variations in the phase of the received signal. The tap weights of the linear predictor are updated using eqn. 6. Finally, the phase estimate at the output of the linear predictor is computed by

\[
\hat{\phi}(n) = \chi^T(n)\hat{\gamma}(n) \tag{8}
\]

**Conclusions:** A receiver structure has been proposed for Doppler-frequency compensation based on linear prediction. The underlying principle of the receiver algorithm is that of the ability to predict future variations in the phase of the received signal. The performance of the linear predictor was demonstrated in combination with a DFE receiver in wideband channel with Rayleigh-fading coefficients.

**References**


**Measurement of building transmission loss using wideband radio channel sounding**

Y.I.C. de Jong, M.H.J.L. Koolen and M.H.A.J. Herben

A method is presented for the fast and accurate measurement of the field due to transmission through buildings. The method enables the separation of this field from other multipath contributions in the time domain. Results of a typical measurement are shown and compared with values generated using a simple transmission model.

**Introduction:** The deployment of urban microcells is a likely next step in the efforts of mobile operators toward higher-capacity networks. In microcells, the base stations are normally located well below the average rooftop level, so that the radiated power is confined to a small coverage area, and propagation over buildings is insignificant. Further, as the line-of-sight is often obstructed, propagation via reflection, diffraction, scattering and also transmission through buildings can become significant. Ray-tracing propagation prediction tools, based on suitable models of these propagation mechanisms, can be used to estimate the field strength distribution around each base station. Propagation research for microcellular communications has so far been focused mainly on the modelling of reflection and diffraction. Only a few experimental investigations of transmission through buildings and the associated losses have been reported [1 - 4].

**Fig. 1 Illustration of building transmission model**

In measurements of building transmission loss, the disturbing effect of multipath contributions entering the receiving antenna via objects in the environment of the considered building forms a major concern. A solution to this problem may be found in the use of wideband and/or directional measurement techniques, which offer the possibility to separate multipath waves on the basis of their different propagation delay times and angles-of-arrival, respectively [5]. Using a combination of these techniques, it was demonstrated in [4] that it is indeed possible to distinguish...
the radio waves transmitted through an obstructing building from other multipath contributions in a realistic microcell environment. However, important practical disadvantages of this method are the relatively complex measurement procedure and the long time needed to measure the transmitted field, even for a single receiver location. This Letter presents a fast, simple and yet accurate method to measure the transmitted field along a trajectory behind an obstructing building, using a wideband radio channel sounder. Results of a typical measurement are shown and compared with values generated using a simple building transmission model.

Transmission model: To first order, the field due to transmission through a building can be modelled as if it were the result of a single 'transmitted ray' propagating directly from the source through the building to the observation point, as shown in Fig. 1. The building transmission loss, defined here as the loss associated with this ray path relative to the free-space loss, can be modelled as the sum of all losses due to the building along the transmitted ray trajectory. These losses include the transmission losses at the two interfaces between the building interior and free space, formed by the exterior walls, and all remaining losses due to obstructions inside the building, conveniently accounted for by a specific attenuation factor \( \alpha \) (expressed in dB/m). Hence, the building transmission loss can be written as

\[
L_b = \alpha \cdot d_{bb} - 40 \cdot \log [T(\theta)] \text{ dB} \tag{1}
\]

where \( d_{bb} \) is the length of the transmitted ray trajectory inside the building, \( T(\theta) \) is the transmission coefficient associated with the exterior walls, and \( \theta \) is the incidence angle defined in Fig. 1. For \( T(\theta) \) we use Fresnel's soft transmission coefficient

\[
T(\theta) = \frac{2 \sin \theta}{\sin \theta + \sqrt{\epsilon_r} - \cos^2 \theta} \tag{2}
\]

in which \( \epsilon_r \) denotes the complex relative permittivity of the exterior walls. This coefficient is valid for vertical polarisation.

Fig. 2 Plan view of measurement environment

Fig. 3 Measured power delay profiles along trajectory

Measurement: Using the wideband channel sounder described previously in [5] (which operates at 1900 MHz and has a temporal resolution of 20 ns), a measurement was carried out along a straight trajectory behind a 15 m high office building on the EUT campus (Fig. 2). The major part of this building consists of small offices separated by brick walls, with wooden doors opening to a central corridor. A large restaurant hall is situated in the right part of the building. The building has a concrete, metal and glass external construction. The transmitting antenna, which was located at 6.5 m above the ground level, was a 12dBi omnidirectional antenna with a vertical 3dB beamwidth of 6°. A 2dBi sleeve antenna on the roof of a measuring vehicle (6 m above the ground level) was used for reception. Prior to the experiment, high-resolution elevation measurements [5] were performed at several positions along the trajectory, which showed that rooftop propagation was negligible.

Impulse response data were recorded every 0.1 s while the vehicle was moving along the trajectory at a constant speed of 1.4 m/s. The resulting set of power delay profiles, which is denoted by \( \rho(z, d) \), \( \tau \) being the propagation delay time and \( d \) the distance along the trajectory, is shown in Fig. 3. For each \( d \) the values of \( \tau \) for which \( \rho(z, d) \) has local maxima form estimates of the propagation delays of the dominant multipaths. The value of \( \rho(z, d) \) at each of these \( \tau \) is proportional to the multipath intensity. The proportionality factor between the two can be determined by connecting a known attenuation between the transmitter and the receiver.

The received field is composed of several multipath waves propagating around the building via reflection, diffraction and scattering from surrounding objects, and a contribution due to transmission through the building. The waves propagating around the building arrive at the receiving antenna roughly from the front and back of the vehicle. As the distance along the trajectory increases, the profile maxima corresponding to these waves move along the delay axis at an approximately constant rate (see Fig. 3). The sign of this rate depends on whether a wave propagates around the left or the right side of the building. In Fig. 3, the transmitted contribution can easily be identified by its hyperbolic shape, and because it has minimum delay for all \( d \). The solid line represents the theoretical delay \( \tau_c(d) \) associated with the transmitted ray, and is in very good agreement with the measured delay of the transmitted contribution. The absolute transmitted field strength, required to determine \( L_b \), is obtained from \( \rho(z, d) \) by setting \( \tau = \tau_c(d) \) and multiplying by the found proportionality factor.

Fig. 4 Measured and modelled building transmission loss \( L_b \)

Fig. 4 shows the measured building transmission loss, together with theoretical values of \( L_b \) computed using eqn. 1 with \( \alpha = 5 \) and \( \alpha = 1.1 \text{ dB/m} \). To compute the theoretical \( L_b \), the building was modelled as a rectangular box having approximately the same length and width. The length of the building, which for this measurement was 6 m, was obtained by applying a 40-wavelength averaging window, and the attenuation factor \( \alpha \) used in eqn. 1 was chosen so as to minimise the RMS error with respect to the averaged data. For \( \alpha = 1.1 \text{ dB/m} \), this error is 4.4 dB. The RMS error can be reduced by using different values of \( \alpha \) for the left and the right half of the building, thus reflecting the fact that there are more internal walls in the left section (see Fig. 2).

Conclusions: A fast, simple and accurate method for measuring the field due to transmission through buildings has been presented. The general trend of the results obtained using this method can be
Measurements of distortion and depolarisation of millimetre pulse waves propagating in randomly distributed scatterers

T. Tazaki and T. Oguchi

The distortion and depolarisation of millimetre pulse waves, propagating in large spherical water scatterers, have been measured in order to determine the effect of multiple scattering on the pulse shape. These measurements have been found to confirm with the previously published theoretical results for a rain medium, although the scattering parameters are different.

Introduction: In radiowave communications through rain, the transmission characteristics must be sufficiently good to satisfy the requirements of the system under consideration. In modern communication systems, the transmitted signals are commonly pulse modulated. Several authors have investigated the problems associated with pulse propagation in random media. Some authors used a two-frequency mutual coherence function to solve the multiple-scattering problems for a scalar wave incidence [1]. In the work presented in [2], a two-frequency radiative-transfer was used to study the effect of multiple scattering on the distortion and depolarisation of microwave and millimetre pulse waves in rain [2]. This study showed that the distortion of a microwave pulse is insignificant even at an optical depth of seven at a rainfall rate of 150mm/h. Although a cross-polarised incoherent pulse was generated and underwent both distortion and time delay, its intensity was very small. In the work presented in this Letter, we measured the distortion and depolarisation of a millimetre pulse wave to confirm whether the previous results are valid under strong multiple-scattering conditions. The shape, as well as the depolarisation, of millimetre pulse waves propagating in randomly distributed spherical water scatterers were measured at 30GHz.

Transmission measurements: The polarisation state of the transmitter was vertical, and both copolarised and cross-polarised responses at 0° and 20° canting angles were measured. As in the backscattering measurements, 32 different scatterer configurations were measured. In radiowave communications, the instantaneous signal fluctuation is an important factor for assessing the communication quality of a channel, while in radar measurements the averaged amplitude and phase of several data samples are subjected to analysis. Fig. 1 shows several examples of the intensity of the copolarised transmitted pulse for each scatterer configuration. The canting angle of the scatterer was 0°. The vertical bar on each curve shows the peak point of the curve. The number attached to each curve shows the data number in the 32 data samples. The dashed curve shows the shape of the received pulse wave.

Table 1: Major scatterer parameters

| Dimension of water-injected spheroids | Major semi-axis | 12.5mm |
| Minor semi-axis | 10mm |
| Polystyrene shell thickness | 0.2mm |
| Average number density | 1,190.7 scatterers/cm² |
| Forward-scattering amplitude of spheroidal scatterer at 30GHz (calculated) |
| Horizontal polarisation | -0.37117 × 10⁻¹ (0.40516 × 10⁻¹) |
| Vertical polarisation | 0.14236 × 10⁻¹ (0.41228 × 10⁻¹) |
| Refractive index of styrofoam blocks at 30GHz (measured) | 1.006 (imaginary part is of order of 10⁻¹) |