On the modelling of electromagnetic wave scattering by a row of cylinders

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ON THE MODELLING OF ELECTROMAGNETIC WAVE SCATTERING
BY A ROW OF CYLINDERS

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Abstract
The scattering of electromagnetic (EM) waves incident upon a row of metallic circular cylinders is analyzed. Experimental results are presented and compared with computer simulations based on the Uniform Theory of Diffraction (UTD). It is demonstrated that the single-cylinder UTD-model presented in [1] is an efficient tool to predict the fields scattered by a row of cylinders, e.g. street lamp-posts, and can therefore be used for the modelling of EM-wave propagation in urban environments.

1 Introduction
The present-day development of mobile-communication systems requires a reliable model to predict the EM-field strength distribution in urban environments. At Eindhoven University of Technology (EUT) the deterministic prediction tool FiPre (Field Prediction) is under development [2, 3]. The present version of FiPre uses the Uniform Theory of Diffraction (UTD) to model EM-wave diffraction at block-shaped obstacles. The advantage of this asymptotic technique for scattered-field computations is that it does not need large computer memory capacity and runtime, so that it can be implemented on a low-cost Personal Computer (PC).

The deterministic model FiPre is best suited for the design of Land Mobile Satellite (LMS) and micro-cellular terrestrial systems, because in those geometries only a limited number of objects surrounding the mobile are of importance in the determination of the field strength at the location of the mobile. To include the ability to accurately calculate the EM-wave scattering from cylinder structures, such as lamp-posts and chimneys, a three-dimensional UTD-based model accounting for the computation of EM-wave scattering by a straight circular cylinder was presented recently [1].

The presence of multiple cylinders on the radio wave propagation path gives also rise to multiply-reflected and multiply-diffracted field contributions, which will be referred to as 'interaction terms'. Elsherbeni and Kishk
presented a method by which the scattered field from multiple parallel cylinders can be calculated including the interaction terms [4]. They applied the boundary value method with plane-wave illumination, and found that for large separations between the cylinders the interaction terms can be neglected.

Our UTD-based method also demonstrates that the amplitude of these terms decreases with increasing separation of the cylinders [1]. This is due to the diverging character of a wave after being reflected or diffracted by the convex surface of a cylinder. Thus, it seems possible that these terms may be neglected for our specific application.

Since accounting for these interaction terms imposes higher complexity and longer runtime of the field strength prediction tool, it is the aim of this paper to get an impression of the applicability of the efficient single-cylinder UTD-algorithm to a multiple-cylinder configuration which frequently occurs in urban environments, i.e. a row of lamp-posts. Therefore, results of some well-defined experiments will be presented and they will be compared with predictions obtained from UTD-based computer simulations.

2 Experimental setup

At EUT we have the ability to perform indoor bi-static scattering measurements at 50 GHz for the determination of the shielding properties of various obstacles. A schematic diagram and the complete description of the measurement setup can be found in [5]. The information necessary to understand the experimental results to be presented later on is shown in Figure 1. An array of four equidistantly spaced finite-length cylinders was mounted on a rotating table along with the transmitter probe at \( T \). The following non-variable parameters were measured with an accuracy of \( \pm 0.5 \text{ mm} \): \( d_T = 452 \text{ mm} \), \( d_{TR} = 699 \text{ mm} \), \( h_T = 1498 \text{ mm} \), \( h_R = 1443 \text{ mm} \), and \( d_e = 178 \text{ mm} \). The angle span of the receiver probe at \( P' \) was taken \( \psi \in [-12^\circ, 12^\circ] \), with an angular step of 0.1° and an accuracy of \( \pm 0.05^\circ \). The secondary effect of diffraction at the ends of the cylinders was considered not to be important.

The 1.5 GHz mobile-communication frequency was scaled to the 50 GHz frequency used in the experiments. The cylinders used were made of brass and all have identical radii of 2.5 mm, corresponding to 8.3 cm at 1.5 GHz, which is near the radius of commonly used lamp-posts. The separation between the cylinder axes of symmetry was chosen to be 40 mm (approximately 7 wavelengths), which corresponds to 1.3 m at 1.5 GHz. Note that this is much worse than in practical situations, since the separation of lamp-posts is generally substantially larger.

3 Experimental results

The measurements were carried out as a function of the azimuth angle \( \psi \), for various orientations of the array, indicated by the angle in Figure 1. Vertical polarization was used because it was demonstrated in [1] that then the scattered field components are the largest. The received-power results relative to the free-space power are depicted in Figure 2 by the solid curves. The dashed curves are obtained with UTD by simply adding the
individual scattered fields from each cylinder, and thus excluding the interaction terms. Except for the symmetric situation with $\kappa = 0^\circ$, the asymmetry of the curves is clearly visible. For angles $\kappa$ up to $60^\circ$, the UTD-simulation curves correspond quite well with the measured curves. At $\kappa = 80^\circ$, the curves also follow similar courses with coinciding minima and maxima, but large differences in power level are present in the deep shadow region. These are readily explained by the fact that the interaction terms become more significant as the angle between the propagation direction of the incident wave and the longitudinal direction of the linear array decreases.

The measurement with $\kappa = 80^\circ$ was repeated once, without touching any part of the measurement setup. The second measurement result, represented by the dash-dotted curve in Figure 2(e), only slightly differs from the first measurement. This demonstrates clearly the accuracy of the measured results.

4 Conclusions

The single-cylinder UTD-algorithm presented in [1] can also be applied in configurations involving multiple cylinders, provided that the separation between the cylinders is sufficiently large. It was demonstrated that for a separation of 7 wavelengths well-acceptable predictions can be obtained with the single-cylinder approach. Since the separation in a row of lamp-posts or chimneys generally exceeds 7 wavelengths, the single-cylinder UTD-method suffices for the modelling of EM-wave propagation in urban environments, although the scarcely occurring situation with a nearly longitudinally incident wave should be approached very carefully.

References


Figure 1: (a) Side view of the measurement setup; (b) Schematic top view of the corresponding model.
Figure 2: Total received power relative to the free-space power as a function of the azimuth angle $\psi$ for four parallel cylinders at (a) $\kappa = 0^\circ$, (b) $\kappa = 20^\circ$, (c) $\kappa = 40^\circ$, (d) $\kappa = 60^\circ$, and (e) $\kappa = 80^\circ$. ———/--- measurements; ——— UTD-simulations.