FDTD Channel Modelling with Time Domain Huygens' Technique

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***Abstract*— Much interest is currently being shown in mm-wave high data rate, short range communication links. The modelling of these types of links presents considerable challenges. In this paper, a 60 GHz link consisting of two Cavity Backed Slot antennas, the terminals on which they are mounted and the intervening environment, is modelled using an enhanced FDTD technique. This type of problem can be expensive in computer resources because of the existence of small geometrical detail and also a large computational space. To improve on this, the problem is split into three parts which are linked using a Time Domain Huygens (TDH) approach. An improvement of around 56 % is obtained in the overall run time compared to a direct FDTD run. The approach has much potential and is suitable to be applied in larger and more complex communications links.**

I. Introduction

Large electromagnetic problems can be solved by a number of numerical techniques such as Finite Difference Time Domain (FDTD), Transmission Line Matrix (TLM), Method of Moment (MoM), etc [1]. Among those, FDTD is a time domain technique which solves finite difference analogue of the time-dependent Maxwell's equations on a lattice of points [2]. The technique was first introduced by Yee in 1966 [3] and it is especially strong in obtaining large bandwidth results. Although the capacity of the technique is restricted by the size of available computing facilities, it is simple to implement as long as the electric parameters of the structures are known for each point.

For indoor wireless transmission systems, the characteristics of the propagation channel are heavily affected by the operating frequency and the environment and are generally hard to predict. Such predictions are, however, crucial since the scatterers and the obstacles in the channel might lead to coverage problems as well as limiting the maximum data rate due to delay spread [4]. Statistical models, ray tracing and time domain integral equations are some of the techniques for predicting propagation channels [5]. The FDTD method, however, is the more accurate and also has the capability of modelling inhomogeneous materials and non-specular scattering, unlike ray tracing [6]. In addition, frequency dependent antenna properties can also be included in FDTD modelling [7].

Although, in principle, FDTD allows the complete link to be rigorously modelled, the run time becomes impractically long for large scenarios and an alternative approach is necessary. In this paper, a 60 GHz channel, including a transmit and a receive antenna is simulated with an enhanced FDTD technique using software developed by Bristol University's Computational Electromagnetics Group. The run time is decreased by dividing the problem domain into subdomains. This is achieved by applying Huygens' Principle in the time domain. The fields are calculated on the chosen Huygens' surface for one subdomain and these are used as an input for the following subdomain. In [7] an UWB indoor radio channel was simulated and the frequency dependent antenna patterns were taken into account with the same approach. However the frequency band was also divided into subbands and the fields on the chosen Huygens' surface were recorded at discrete frequencies. Here the technique is applied in time domain which makes the technique more suitable for large bandwidth scenarios and also preserves delay profile information in a direct manner.

The paper starts with an introduction to the antennas used. The channel model is then described and finally, the application of the Time Domain Huygens' (TDH) principle is demonstrated. The results obtained by direct FDTD simulations are compared with the results obtained by the application of the Huygens' Algorithm in terms of the time and the frequency domain response of the channel.

II. 60 GHz Antenna

A cavity backed slot (CBS) antenna is designed on Liquid Crystal Polymer (LCP) which is one of most frequently used substrates for millimetre-wave antennas [8][9]. LCP offers good electrical performance and has low cost. The electrical properties of ULTRALAM 3850, dielectric constant of 2.9 and loss tangent of 0.0049 are used in the model [10]. The antenna dimensions can be seen in Fig. 1. More information on the antenna is available in [11].

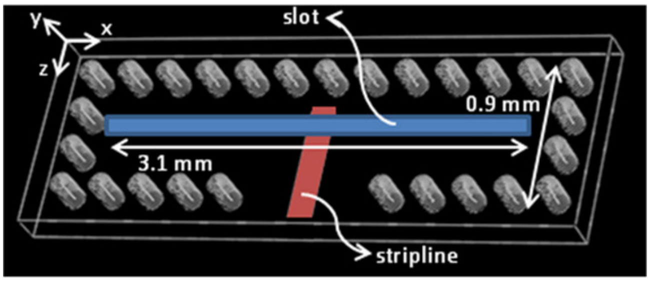


Fig. 1 60 GHz CBS antenna geometry, slot length=3.1mm slot width=0.1mm, cavity width=0.9mm, cavity length=3.6mm

III. DATA LINK MODEL

A short range 60 GHz communications link is modelled with FDTD technique as seen in Fig. 2. The CBS antennas described in the previous section are used for both transmitting and receiving. The separation between the antennas is 2λ (10 mm).

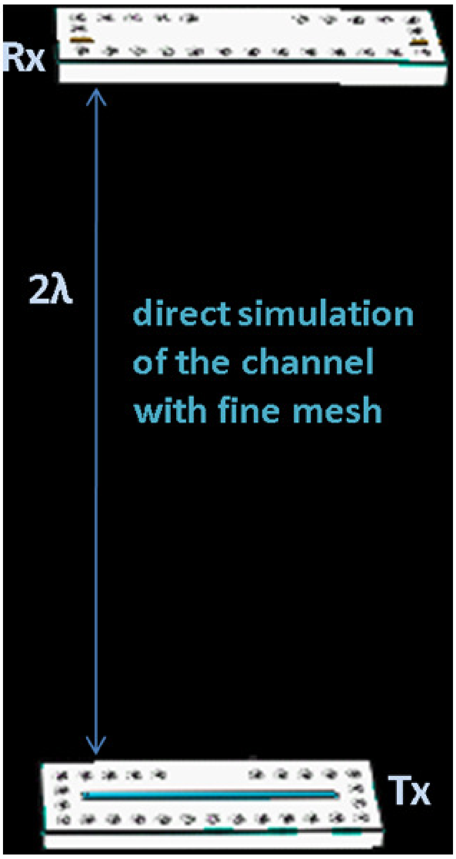


Fig. 2 60 GHz Channel Model, Tx and Rx antennas are facing each other and 2λ(10mm) separation between them

For a direct FDTD run, a computational space having a size of 9x13x6 mm was used and this was terminated using Mur 1st order absorbing boundaries. In order to better model the detail of the antenna, and in particular the curved surfaces of the pins, the Dey-Mittra algorithm was used [12]. This model takes 5 hours and 57 minutes to run with 32800 iterations on an Intel Xeon 5670 processor with 24 GB RAM. The smallest mesh size is 0.01 mm (λmin/500) in order to sufficiently resolve the geometric detail, and the whole model consisted of 9298 thousand cells. In the regions away from the antenna elements, the largest space increment was chosen to be 0.125 mm (λmin/40) which is sufficient to avoid problems arising from numerical dispersion.

IV. APPLICATION OF THE TIME DOMAIN HUYGENS' PRINCIPLE

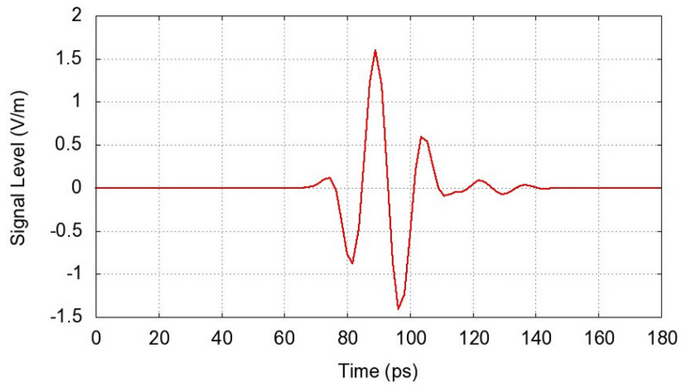
In order to reduce the amount of computer resources needed to analyse the link, the scenario shown in Fig. 2 is split into three sections. These are illustrated in Fig. 8 and are described as follows:

(i) First the transmit antenna is simulated in isolation using a fine mesh as before. At each time step of the simulation, the tangential electric and magnetic fields on the slot are recorded and written to a file for later use. This file is referred to as the "Huygens' snapshot". Because only the antenna is being modelled, the size of the computational domain is small, in this case 9x6.5x6.6mm. Moreover, the simulation may be stopped as soon as the amount of power being radiated drops below a significant value. The number of time steps needed is, therefore, much less than the number which is needed for the complete model in Fig. 2.

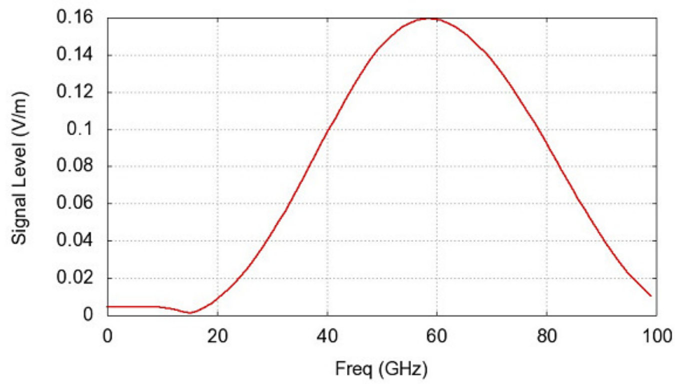
(ii) In the second step, the full structure is modelled but with a mesh which is much coarser than would be needed in a direct FDTD simulation, and therefore faster to run. For this step, the details of the antenna do not need to be accurately represented since the Huygens' snapshot, produced in step 1 will be used for excitation. During this part of the simulation, the tangential electric and magnetic fields on the slot of the receiving antenna are recorded and written to a file. This is the second Huygens' snapshot.

(iii) Finally for the third step, the receive antenna is modelled in isolation using a fine mesh and is excited at the slot by the second Huygens' snapshot. As in step 1, the computational domain in this case is much smaller than for the whole structure so that the required computational resources are much less. The resulting field at the receiving antenna feedline will provide a prediction of the transient response of the communications link.

The excitation waveform is chosen as a raised cosine modulated sinusoid which is centred at 60 GHz. The excitation is applied at the edge of the microstrip line and it is observed by a probe positioned in the neighbouring FDTD cell along the line. The time and frequency content of the signal are shown in Fig. 3(a) and (b).



(a)



(b)

Fig. 3The excitation waveform in time (a) and frequency (b) domains

V. Results

In order to demonstrate the performance of this technique, the link shown in Fig. 2 is simulated both with direct FDTD and also the Time Domain Huygens method. In each case, there are two probes detecting the E field values in the time domain at the points labelled in Fig. 8. The predicted field strengths at the positions of these probes using direct FDTD and the TDH approach are compared in Fig. 4 and Fig. 5. As can be seen in these figures, the results using TDH are very similar to those produced using direct FDTD.

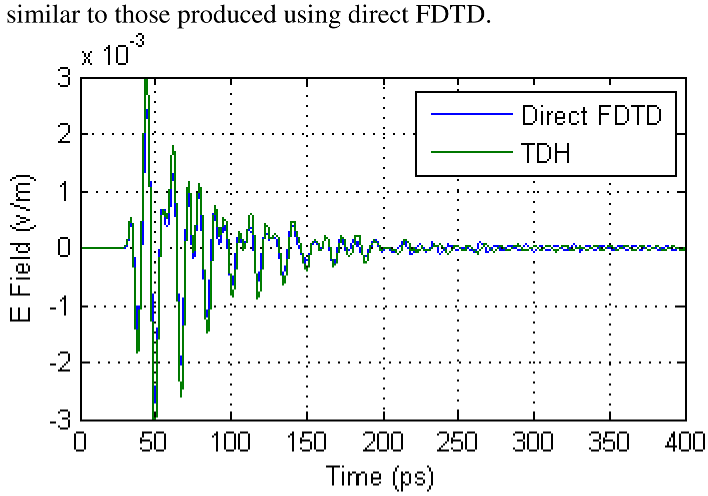


Fig. 4 Verification of the Huygens' technique at step 2, E field variations at Probe #1

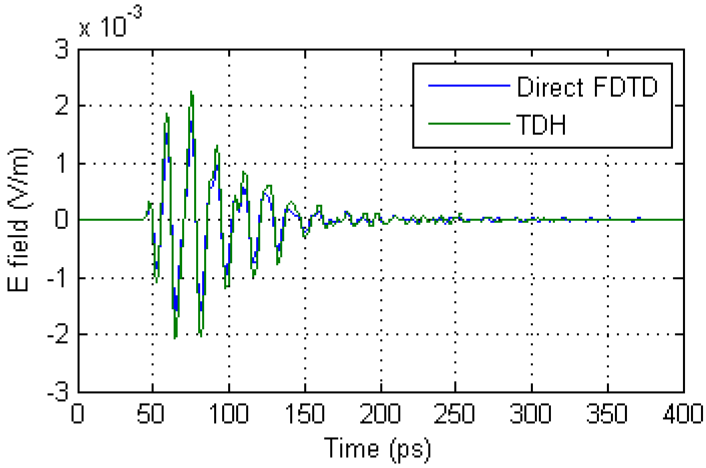


Fig. 5 E field variations at Probe #2

The transient response as seen at the feed line of the receive antenna predicted by direct FDTD and the TDH approach is shown in Fig. 6. Again it can be seen that the timing is very accurate while the TDH results are somewhat higher. The frequency domain results generated using the signals at the antenna ports can be seen in Fig. 7. Here the overall response is similar although TDH underestimates the response by approximately 2.1 dB at 60 GHz.

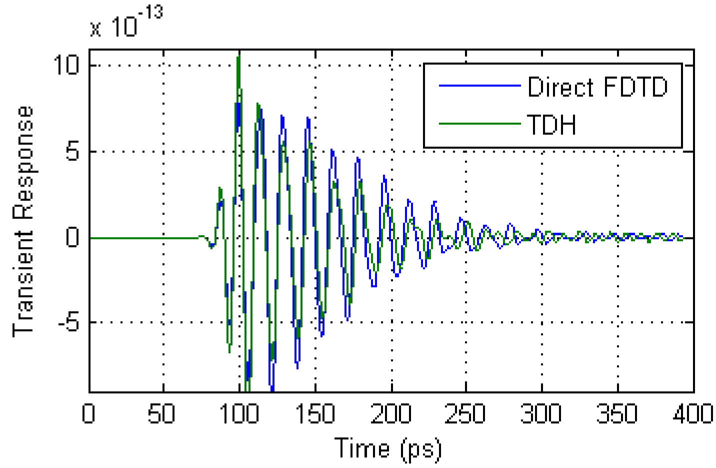


Fig. 6 The transient response as seen in the receive antenna obtained with Huygens' Technique and direct simulations

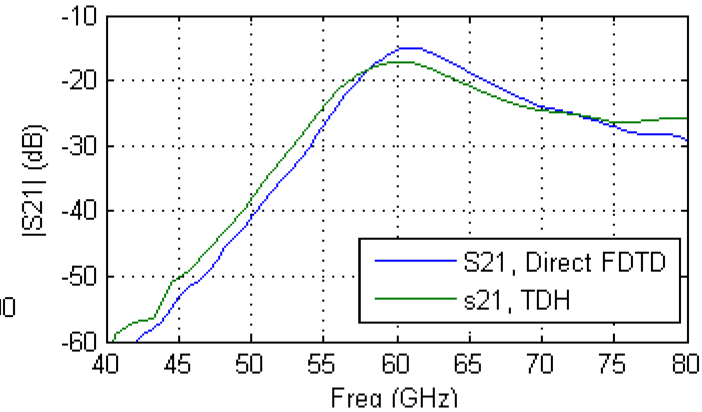


Fig. 7 Verification of the Huygens' technique at step 3 with the frequency response of the channel

In total, all three steps of the Huygens' run take 4 hours 44 minutes while the direct run lasts for 2 hours and 38 minutes, representing a 56% saving. Moreover the first step of the Huygens' run is common for each different channel scenario as long as the same transmitter is used. So for each channel simulation, the total run time with Huygens' will be reduced to 1 hours 55 minutes (32% of the direct run) once the first step is run for the first time. Note that the second step takes 37 minutes and the third step takes 1 hour and 18 minutes on an Intel Xeon X5670 processor. In a more complicated environment where there are other objects in the vicinity of the two antennas, a greater time improvement would be expected.

VI. CONCLUSIONS

A method of analysing a complete short-range, high-speed communications link by means of the FDTD and TDH techniques has been demonstrated for an example problem. The technique is shown to be very powerful for modelling inhomogeneous media and small objects and details. By splitting the problem into three parts which are linked using Huygens' surfaces, an improvement in computer resources of 56% is achieved. It is expected that, for more complicated scenarios, the saving in computer resources would be even greater. This approach has great potential for large bandwidth scenarios and can be applied in more realistic channel modelling.

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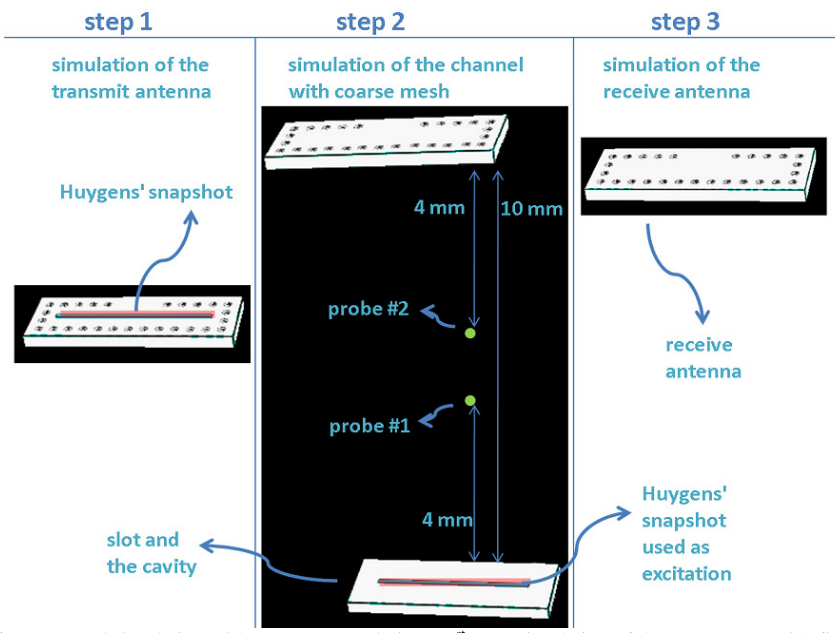

Fig. 8 The three steps of the channel simulation with Huygens' Technique, 1st step: simulation of the Tx antenna with fine mesh, 2nd step: simulation of the whole scenario with coarse mesh, 3rd step: simulation of the Rx antenna with fine mesh.