# Real-Time S-MRTD Simulation of Electrically Large Indoor Wireless Channels with Commodity GPUs

Gerard S. Baron*[1], Costas D. Sarris[1], and Eugene Fiume[2]

[1] The Edward S. Rogers Sr. Department of Electrical and Computer Engineering,
[2] Department of Computer Science, University of Toronto, Toronto, ON, Canada

Asymptotic and statistical models have been the only practical means, in terms of cost, performance and accuracy, for simulating electrically large environments. We show, in practice, how the combination of commodity Graphics Processing Units (GPUs), and higher-order scaling function based Multi-Resolution Time-Domain (S-MRTD) techniques realize an unprecedented high-fidelity full-wave simulator that is orders of magnitude faster (134×) than otherwise previously possible.

## Introduction

Time-Domain simulations are among the highest fidelity methods of electromagnetic simulation. Computationally exhaustive, they have been deemed impractical for electrically-large problems. Recent developments in commodity graphics hardware acceleration provide functionality that dramatically speed-up time-domain simulations [1, 2, 3]. First demonstrated by [1] for 2D isotropic medias, in [2] we extended that work to more complex media equations in a manner purposely addressing known challenges with General Purpose Computing on Graphics Hardware (GPGPU) [4] for the computational electrodynamics community. We would then demonstrate how S-MRTD techniques are ideally suited to GPU acceleration for even greater speed-ups [3]. Not only do they optimally address memory utilization, but its usual shortcoming of increased processing per-cell is in fact an advantage on GPU architectures. This work employs the methodology of [3] to demonstrate a high-performance real-time S-MRTD simulator for indoor wireless channels.

## An Indoor Wireless Channel

We modeled the $\{15.36 \times 15.36\}$ m$^2$ floorplan illustrated in Figure 1(a). Developed by [5], it is comprised of 6 to 8 cm thick walls with isotropic conductivities of $\sigma = 0.002$ $\Omega^{-1}$ and electrical permittivity of $\epsilon_r = 2.89$ in an environment otherwise composed of free space. The space was discretized with $\Delta x = \Delta z = 0.02$ cm into a $\{768 \times 768\}$ cell square mesh. Sixteen layer perpendicular UPML absorbing boundaries were defined along all four edges and backed by PEC walls. The UPML conductivity profile was chosen to have a fourth order polynomial scaling ($m = 4$) and reflection coefficient of $e^{-16}$. Excitation was provided at $t = 0$ by a 2.4 GHz transparent Gaussian point source. Our GPU-accelerated simulation employed a fourth order Deslauriers-Dubuc bi-orthogonal interpolating basis [6] and had a stability factor of $s = 0.5$. Results are presented for a NVIDIA 6800 Ultra PCI/Express GPU with 256 MB of Video Memory and 3.4 GHz Intel Pentium 4 GPU with 1GB of RAM.

## Wideband Analysis

For wideband analysis we used our simulator to determine time invariant *Channel Impulse Responses* (CIRs) [7] at the four test positions depicted in Figure 1(a). The test positions (blue) were chosen to be an equidistany 2.56 m from the source (red) at cardinal compass positions (i.e. North, South, East, West). We sought CIRs for two Ultra Wide Band (UWB) channels nominally centered at 1.0 and 2.4 GHz with bandwidths of 250 and 600 MHz (i.e. 25% carrier frequency) respectively.

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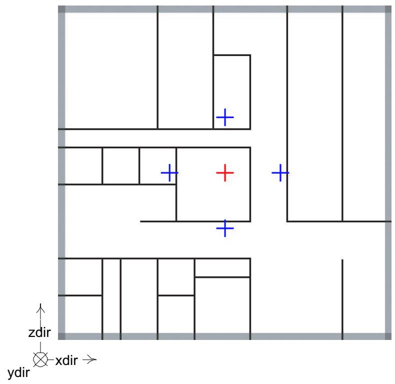
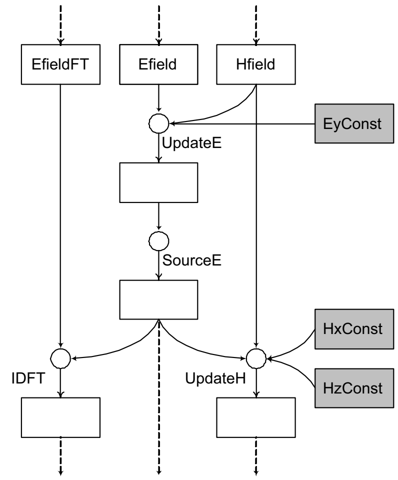


(a) Indoor Floorplan



(b) GPU-Accelerated S-MRTD

Figure 1: An Electrically Large Problem and Its Solution

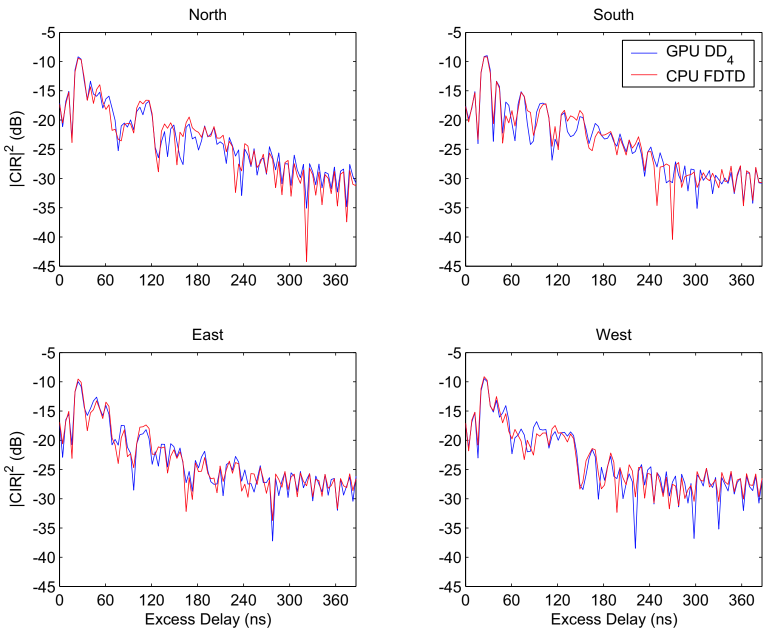
The CIRs were determined post simulation in a three step process. First, the received time-varying signals were transformed to the frequency-domain. Those signals were sampled at a rate coinciding with the underlying simulator's timestep $\Delta t$, over 16364 steps, for a period of 386.44 ns. Their spectra had an ensuing 2.588 MHz resolution. Second, the spectra were normalized by the spectrum of the Gaussian source. The result was then separated into a *Channel Transfer Function* (CTF) for each UWB channel. The ensuing CTFs had 97 and 232 frequency-domain samples respectively. Finally, corresponding CIRs were derived by inverse Fourier transform. By extension, the CIRs had the same number of time domain samples with excess delay bins of 4 and 1.667 ns.

The CIRs apparent at each of the four probe points are depicted in Figures 2(a) and 2(b) for the 1.0 and 2.4 GHz UWB channels respectively. Note that CIRs are complex valued, and their square-magnitudes are termed *Power Delay Profiles* (PDPs). Results derived from our GPU-accelerated $DD_4$ S-MRTD simulation of the $\{768 \times 768\}$ cell mesh, at approximate spatial resolutions of $N_\lambda = 15$ and $N_\lambda = 6.25$, are illustrated in blue. For comparison, results derived from a reference CPU FDTD simulation scaled to $4\times$ the spatial resolution are shown in red. With a sixteenth as many cells and a fourth as many timesteps (constant stability factor), the GPU-accelerated simulation is able to realize PDPs correlated to within 98% and 90% of the CPU results in 1/134 of the time (i.e. 17.25 minutes verses 38.53 hours). It is important to note that the GPU lacks the memory to perform such a FDTD simulation, and that the equivalent S-MRTD simulation run on the CPU would only realize a $4.46\times$ speed-up.

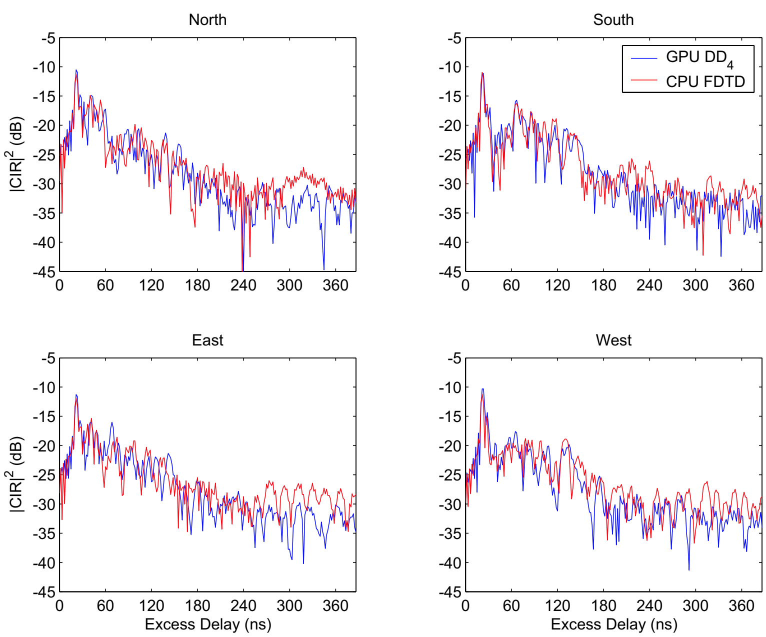
## Narrowband Analysis

For narrowband analysis our simulator was used to determine the transmitted signal's coverage at 1.0 and 2.4 GHz. For every cell in the floorplan, we would calculate the localized magnitude of the received signal's spectra. To save memory an Iterative Discrete Fourier Transform (IDFT) was computed during the simulation as opposed to after it. Governed by (1), the IDFT is functionally similar to updating field state.

$$ {}_{n}IDFT(\mathcal{E}^{y}_{i,k}(2\pi f)) = {}_{n-1}IDFT + {}_{n}E^{y}_{i,k} \cdot e^{-\hat{j}2\pi f(\frac{T \cdot n}{N})} \tag{1} $$




(a) 1.0 GHz UWB Channel

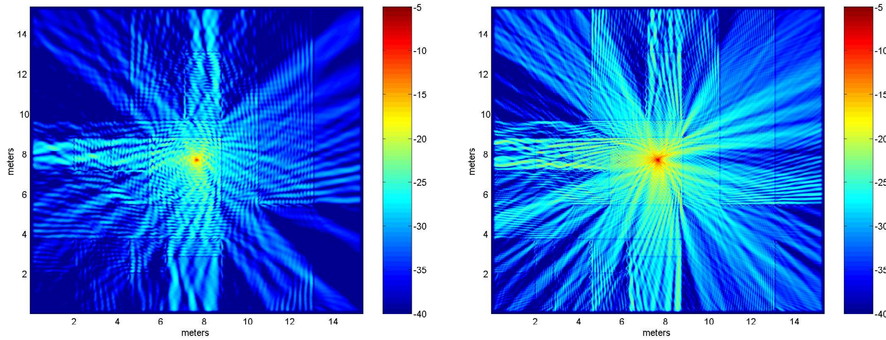



(b) 2.4 GHz UWB Channel

Figure 2: Wideband Analysis: Normalized PDPs

In fact it is sufficient to both evaluate and accumulate the transform's terms as an extra step of a simulation's "leap-frogging" process. By extension, the IDFT constitutes an excellent example of stream amendable analysis that can compound the performance advantage of GPU-accelerated simulators.

Figure 1(b) illustrates how we augmented our simulator's design [2, 3] to realize a stream-based IDFT analysis pass. Therein EfieldFT depicts a so-called uniform texture object representing the present cumulative sum $_{n}IDFT$. For our analysis, it is updated one per timestep and is of the same dimensions as the field textures.




(a) 1.0 GHz Narrowband Channel (b) 2.4 GHz Narrowband Channel

Figure 3: Narrowband Analysis: Average Power Distribution

In relation the IDFT shader implements the right-hand side of (1). It is responsible for evaluating ${}_nE^y \cdot e^{-\hat{j}2\pi f(\frac{T\cdot n}{N})}$ at the present timestep and blending the ensuing value with the EfieldFT texture.

Illustrations of the 1.0 and 2.4 GHz narrowband channel coverage are depicted in Figures 3(a) and 3(b) respectively. These figures reflect the average received power over a period of $T = 193.22$ ns starting at $t = 0$. A resulting $N = 8192$ samples were ultimately used in the IDFT. Again we understand these figures to be as accurate as an equivalent GPU FDTD at $4\times$ the spatial resolution with a comparable speed-up.

## Conclusion

We have demonstrated the application of a GPU-accelerated S-MRTD simulator to a hitherto intractable electrically large simulation of signal propagation in an indoor wireless channel. The unprecedented combination of the simulation's low-cost, high-performance, and high-fidelity points to the possibility of interactive design tools for wireless network planners. Future work includes an extension to 3D environments.

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