5 Simplification Techniques for full Wave Antenna Modelling with a Human Phantom

5.1 Introduction

In this chapter the Equivalence Principles Method (EPM) [5.1], [5.2] is employed to study the human exposure located in the near-field of a HF curtain array antenna. EPM is shown to reduce the computational time by at least a factor of 10 when compared the Finite Integration Technique (FIT) [5.2]. However the E-field values predicted by the two methods vary by approximately 3dB in the vicinity of the modelled Skelton C HF curtain array antenna 766.

5.2 Hybrid numerical method

A hybrid approach based on the Method of Moments (MoM) [5.5] and Finite Differential Time Domain (FDTD) [5.6] was considered in previous chapters. In Chapter 4 the hybrid approach was used for the study and modelling of the high power Skelton C HF curtain array and its supporting structures. The effects of near-field electromagnetic radiation on the human body, taking ground conditions into account, have also been studied [5.7]. Other numerical methods (MoM and FDTD) have their strengths and limitations as discussed in Chapter 2.

CST Microwave Studio and the Numerical Electromagnetic Code (NEC) [5.8] are both commonly used commercial computational electrodynamics modelling software packages. CST Microwave Studio uses FIT for full-wave 3D EM analysis and NEC uses MoM for modelling wire and surface antennas. FIT uses Maxwell's partial differential equations (PDE) and integral equations, while FDTD uses differential equations. Both methods demand high computational resources (CPU speed and RAM size) to solve large problems. In comparison with CST, which employs FIT, MoM is computationally less intensive for large scale simulations, but is less efficient for calculating dielectric volume discretisation problems such as whole-body or localised SAR.

This chapter considers the potential of the Equivalence Principles Method for reducing the high computational resources necessary for HF near-field exposure modelling. The Equivalence Principles Method combined with FIT have been assessed using CST Microwave Studio with the aim of seeking an alternative, faster, and less computationally intensive approach, for accurate calculation of whole body Specific Absorption Rate (SAR) and exclusion distances related to HF transmission sites.

5.3 Full scale modelling and equivalence principles

An investigation of the Equivalence Principles Method is made to assess its suitability for calculating E-field values in the near-field of the HF curtain array antenna for human exposure. The Field Source implemented in CST Microwave Studio is based on the Equivalence Principles Method [5.2], [5.9].

The Equivalence Principles Method is a three dimensional representation of the surface equivalence theorem. This theorem replaces electromagnetic sources by equivalent ones. The fields outside an imaginary closed surface are obtained by placing suitable electric and magnetic current densities over the imaginary closed surface. These current densities must satisfy the desired boundary conditions [5.9]. The current density values are chosen so that the resultant fields are zero within the closed surface and equal to the radiation produced by the actual electromagnetic sources outside the closed surface. The technique can be used to obtain the fields radiated by sources enclosed within a closed surface.

For example, consider an electromagnetic field (E_1, H_1) in free space, generated by the physical electric and magnetic current sources J_1 and M_1. If we now assume that J_1 and M_1 are removed, a new field (E, H) now exists inside our imaginary surface. The imaginary surface acts as a closed source S. The electric and magnetic currents flowing outside the closed surface S must still satisfy the electromagnetic field boundary conditions on the tangential E and H fields theoretically using Green’s theorem as defined by [5.2]:

$$J_s = \hat{n} \times (H_1 - H) \quad (1)$$

$$M_s = \hat{n} \times (E_1 - E) \quad (2)$$

Where $\hat{n}$ is the unit outward normal vector to the closed source S.

A model of the Skelton C HF curtain array antenna 766 with its supporting towers, as used by the BBC World Service at 6-7 MHz, is shown in Fig 5.1. This array has 12 horizontal elements; it is approximately 100m tall and 100m wide. If we consider that a $2mm^3$ voxel size may be required for SAR calculations, it becomes clear that significant computational resources will be required in order to make accurate calculations. The benefits of using less computationally demanding techniques are now evident.

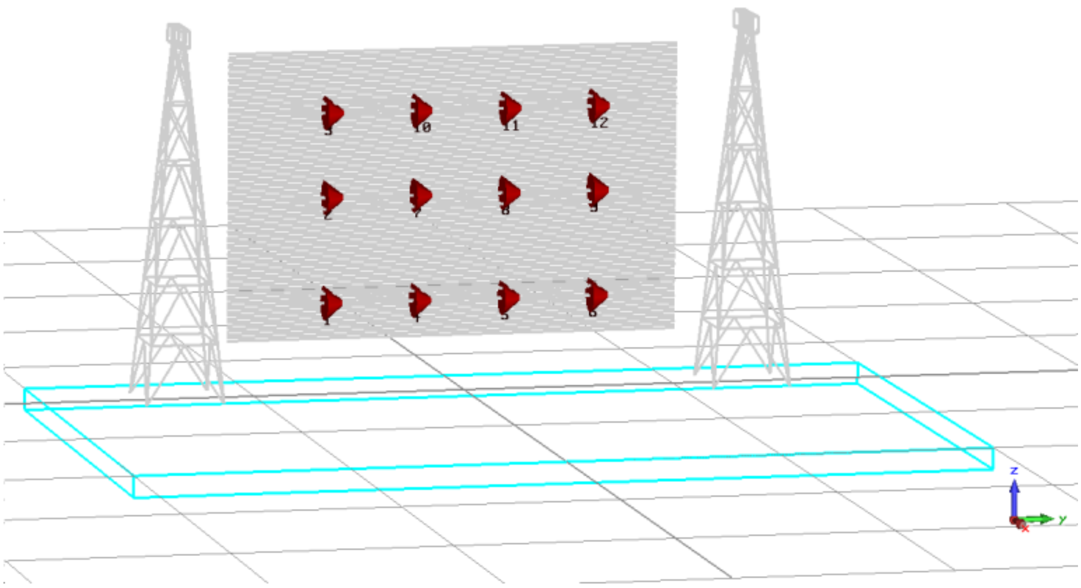


Fig 5.1 CST model of Skelton 'C' HF curtain array (6-7MHz) and its towers.

Fig 5.2 illustrates the differences between the FIT and the Field Source (Equivalence Principles Method) applied to the near-field HF exposure model. In the traditional FIT case (Fig 5.2a), each time the model is modified e.g. changing the location of a human phantom to calculate full body SAR, the entire simulation space including the HF curtain array antenna has to be recalculated. For the Field Source implementation (Fig 5.2b), the simulation space is divided into two regions whereby the E-fields within the area surrounding the 12 elements of the HF array are calculated only once.

Subsequently, each time the location of the human phantom is changed, only the remaining simulation space is recalculated.

This is of benefit once the E-field distributions of the HF curtain array antenna and its surroundings have been calculated and mapped. The location of 'hot spots' which contain high vertical or horizontal E-field components can be selected for positioning the anatomical human phantom for further coupling and exposure level research such as SAR calculation. Typically in excess of 10 phantom locations may be required for analysis. By separating the simulation into these two steps rather than one large simulation for each scenario it is possible to significantly reduce the computation time and computing hardware requirements.

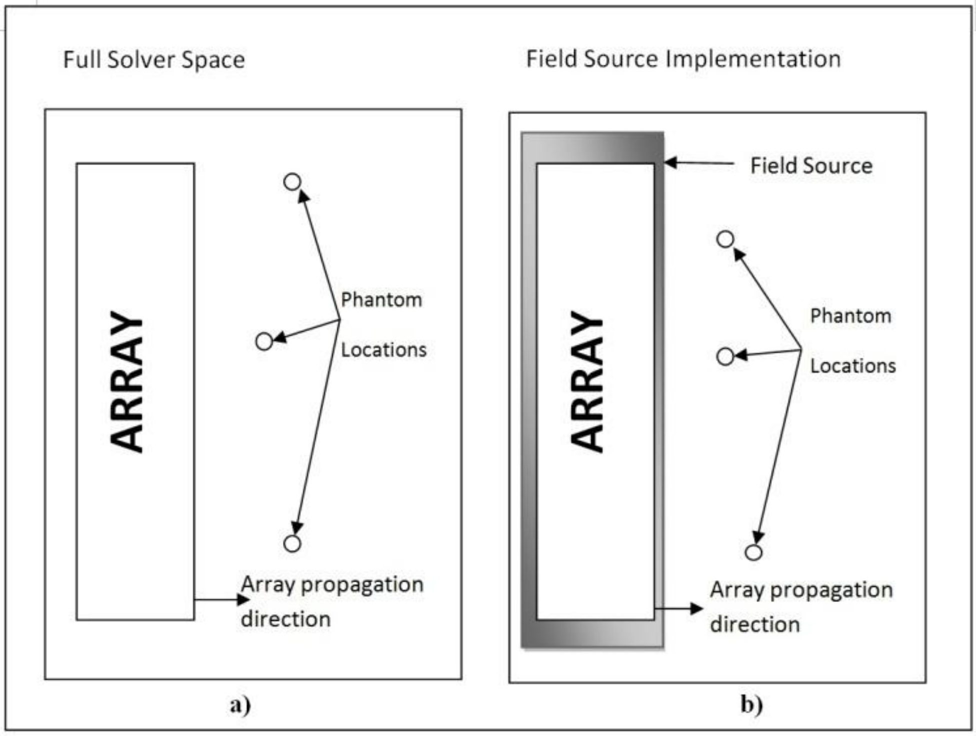
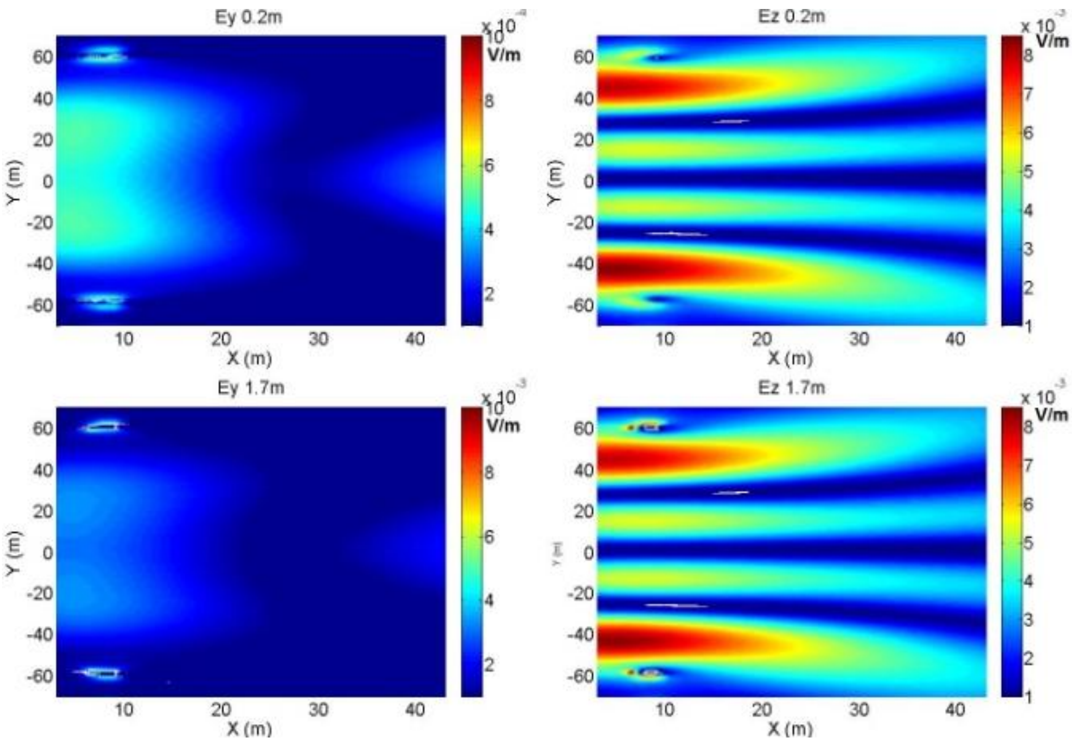


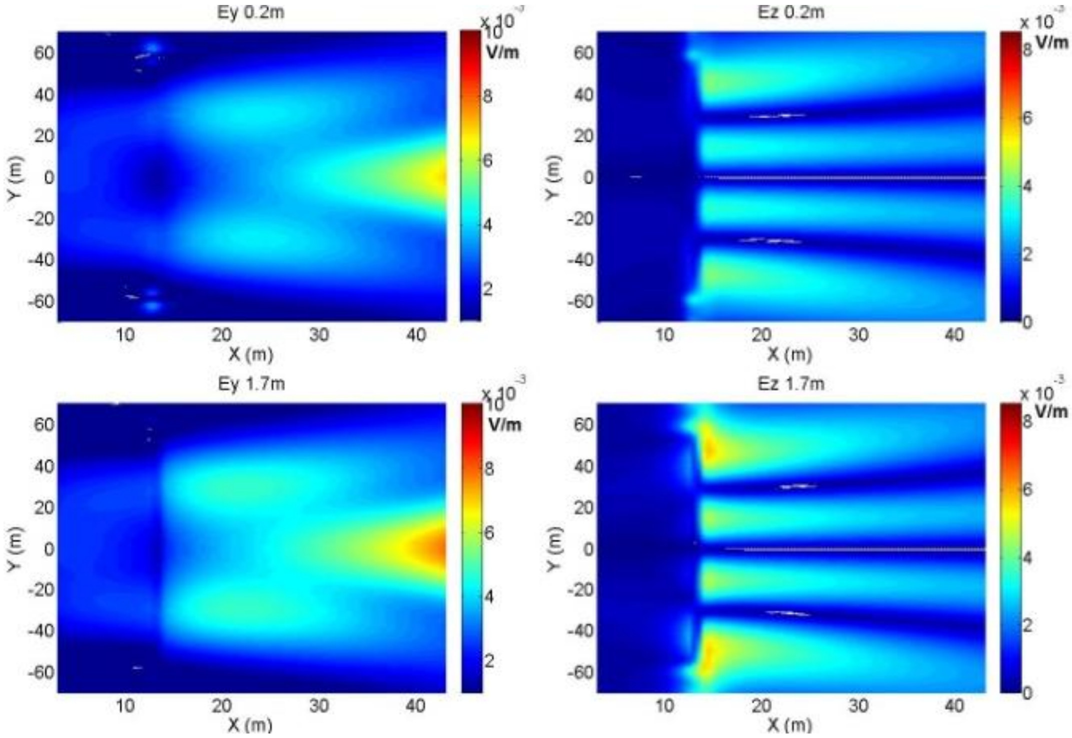
Fig 5.2 a) for each phantom location the entire simulation space has to be recalculated b) with Field Source implementation it is no longer necessary to re-simulate the 12 elements array for each new phantom location.

All of the simulations were performed using CST Microwave Studio installed on a quad core workstation having a 3 GHz CPU and 64 GB of RAM and one NVIDIA C1060 Tesla graphics processing unit (GPU). The simulation time for the entire model including antenna, the space in front of the antenna, and a human phantom requires between 2 and 10 days depending on the ground condition and meshing. Furthermore, a high mesh resolution is needed to satisfy the mass value averaging criteria for whole body averaged SAR or local SAR calculations in the phantom. By using the Field Source (Equivalence Principles Method) the computational time is reduced to less than 10 hours.

The E-field distributions generated when the antenna is driven by a 1W source over a perfect conducting ground are presented in Fig 5.3. Results for the traditional FIT solution are presented in Fig 5.3a, while Fig 5.3b presents the solutions obtained using the Field Source (Equivalence Principles Method). Heights of 0.2m and 1.7m above the ground are considered to represent the heights of the ankle and shoulder of an average human male. Vertically and horizontally polarised E-field component are displayed separately at these two heights for comparison. The centre of the array element was aligned along the y-axis at y=0m and direction of wave propagation was along the x-axis. The Field Source was set to encapsulate the whole array, its reflecting screen and the two supporting towers. Comparing the results shown in Fig 5.3, the horizontal component Ey of the radiated electric field appears to suffer the most distortion. Furthermore, the Field Source/FIT interface can be clearly seen in Fig 5.3b.

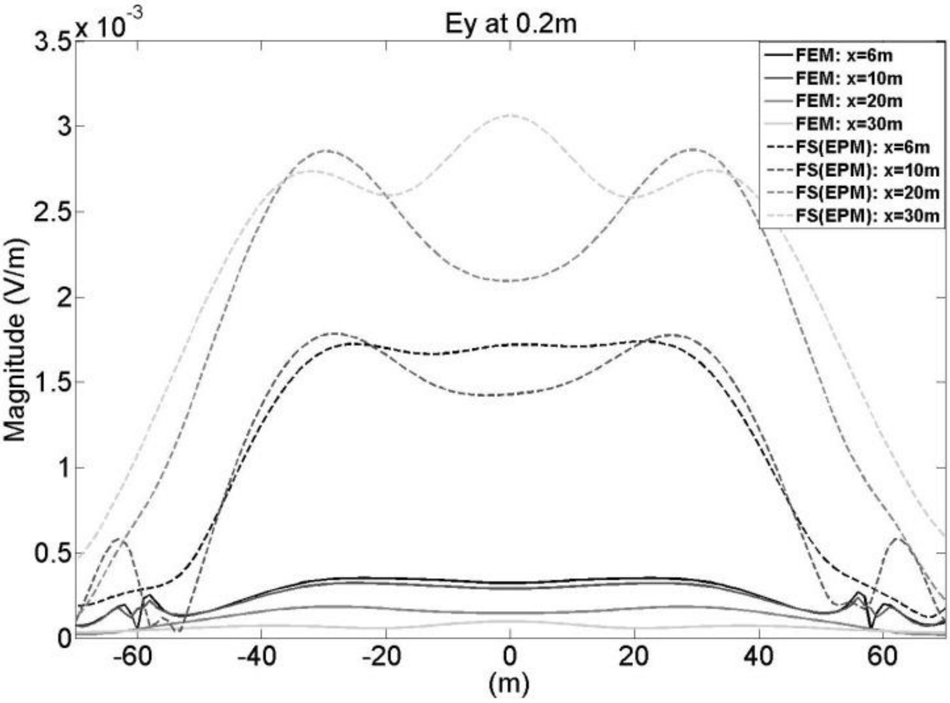


a) FIT

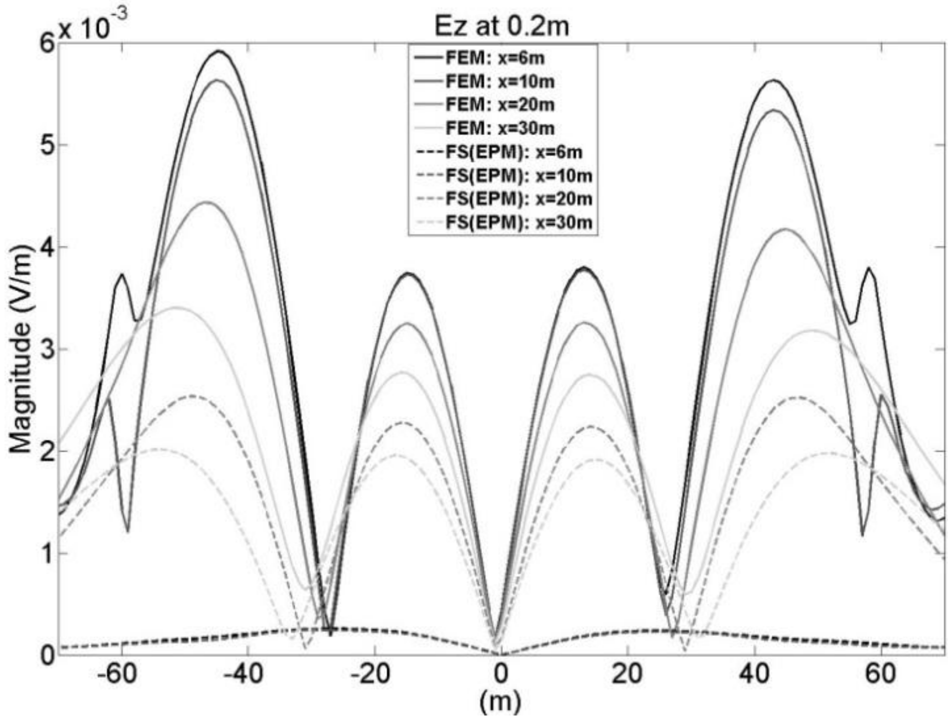


b) Field Source (Equivalence Principles Method).
Fig 5.3 E-field distributions surrounding the HF array calculated using different numerical methods.

Fig 5.4 and Fig 5.5 show 2D line cuts of the simulated radiated E-field for different planes parallel to the front of the array, and perpendicular to the propagation direction. The horizontal and vertical components of the E-field are calculated and compared using a) FIT and b) Field Source (Equivalence Principles Method). Fig 5.4 presents results at 0.2m above the ground corresponding to the height of a human ankle, while Fig 5.5 presents results at 1.7m corresponding to the shoulder height of an average human male. For the horizontal component of the E-field, the Field Source (Equivalence Principles Method) produces results approximately 3dB higher than those obtained by the Finite Element Method, while the vertical component is 3dB lower.

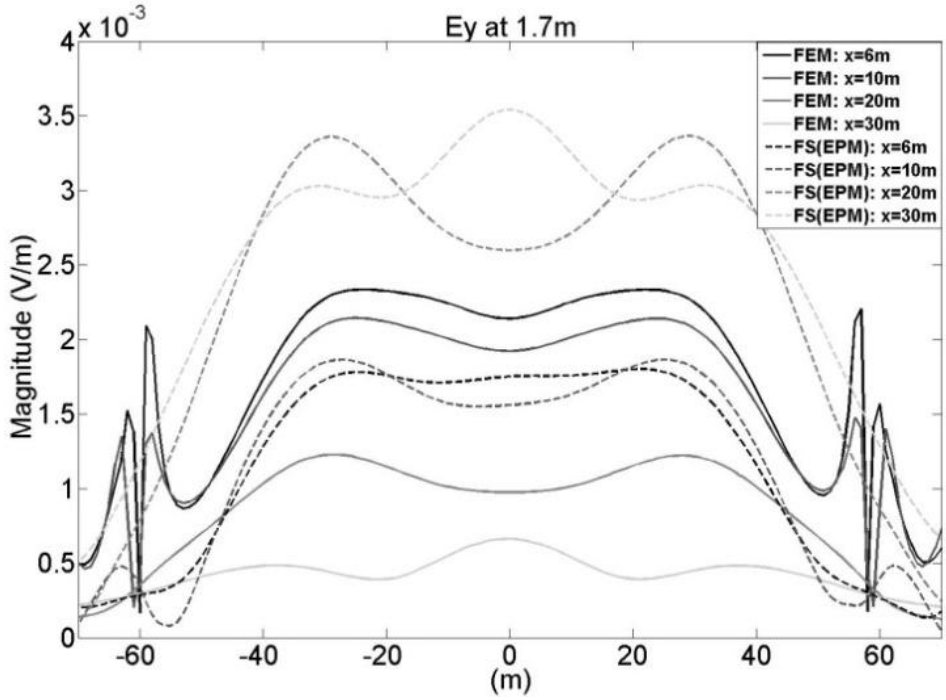


a)

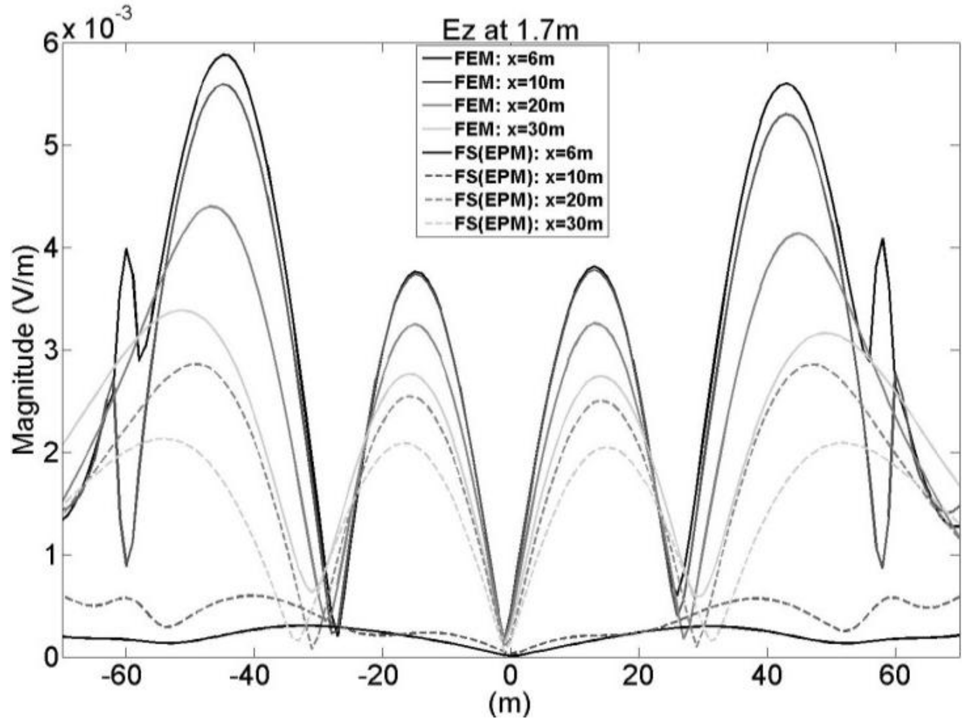


b)

Fig 5.4 A comparison of E-field values at different locations in front of the array showing
a) horizontal Ey and b) vertical Ez, components 0.2m above the ground.



a)



b)

Fig 5.5 A comparison of E-field values at different locations in front of the array showing
a) horizontal Ey and b) vertical Ez, components 1.7m above the ground.

5.4 Conclusions

This work has presented a comparison of E-field values at different locations in front of the Skelton C HF curtain array antenna 766. The results were calculated using both the Finite Integration Technique and Equivalence Principles Method. Results have been presented showing both the horizontal (Ey) and vertical (Ez) components of the E-field at heights above the ground corresponding to the ankle and shoulder of an average human male. The computational time has been reduced by at least a factor of 10 by implementing the Equivalence Principles Method. However the E-field values varied by approximately 3dB in the vicinity of the array when compared to those calculated using FIT. When using a field source to replace the original excitation, based on the equivalence principle, the field outside does not change as long as the outside objects and conditions remain the same. But, the human phantom was an additional dielectric scatterer in the secondary simulations which altered the outside of the field source. There is always interaction between the added scatterer and the original source structure. Therefore, the secondary field was altered. The removal of the original source results in some calculation differences. Furthermore, the initial field values in secondary simulations are defined at a specific spatial discretization by spatial interpolation the original field. These would cause some difference between the original field values and the secondary simulation grid. These calculations can be seen as approximation. In this model the array and supporting tower are electrically large, however for the SAR calculation it still requires quite fine and accurate field results. Therefore the 3 dB variation mainly occurs very close to the array or field source. The area close to the array is the region of interest where the human could have the highest exposure level. These would result in a large margin of error when calculating the SAR for human exposure assessment. However the method may be suitable to solve problems where the human will be located further away from the array.

References

[5.1] D. Merewether, “On implementing a numeric Huygen’s source scheme in a finite difference program to illuminate scattering bodies,” ... , *IEEE Transactions on*, no. 6, pp. 1829–1833, 1980.

[5.2] A.Taflove and S. C. Hagness, *Computational Electrodynamics, The Finite-Difference Time-Domain Method*. Boston: Artech House, 2005.

[5.3] K. . Yee, “Numerical solution of initial boundary value problems involving Maxwell’s equations in isotropic media,” *IEEE Trans. Antennas Propag.*, vol. 14, no. 3, p. 302, 1966.

[5.4] T. Weiland, “A discretization model for the solution of Maxwell’s equations for six-component fields,” *Archiv Elektronik und Uebertragungstechnik*, vol. 31, no. 3, pp. 116–120, 1977.

[5.5] R. Harrington, *Field computation by moment methods*. 1993.

[5.6] “CST MICROWAVE STUDIO®.” CST STUDIO SUITE® http://www.cst.com/.

[5.7] Y. Fu, M. Hate, R. Langley, and J. Rigelsford, *The effects of ground characteristics on near-field modeling of HF transmission sites for EMC compliance testing*. IEEE, 2010, pp. 1–4.

[5.8] G. J. Burke, “Numerical Electromagnetics Code NEC-4 Mothod of Moments Part II: Program Description-Theory,” 1992.

[5.9] “CST Mircrowave Studio Advance Guide.” .