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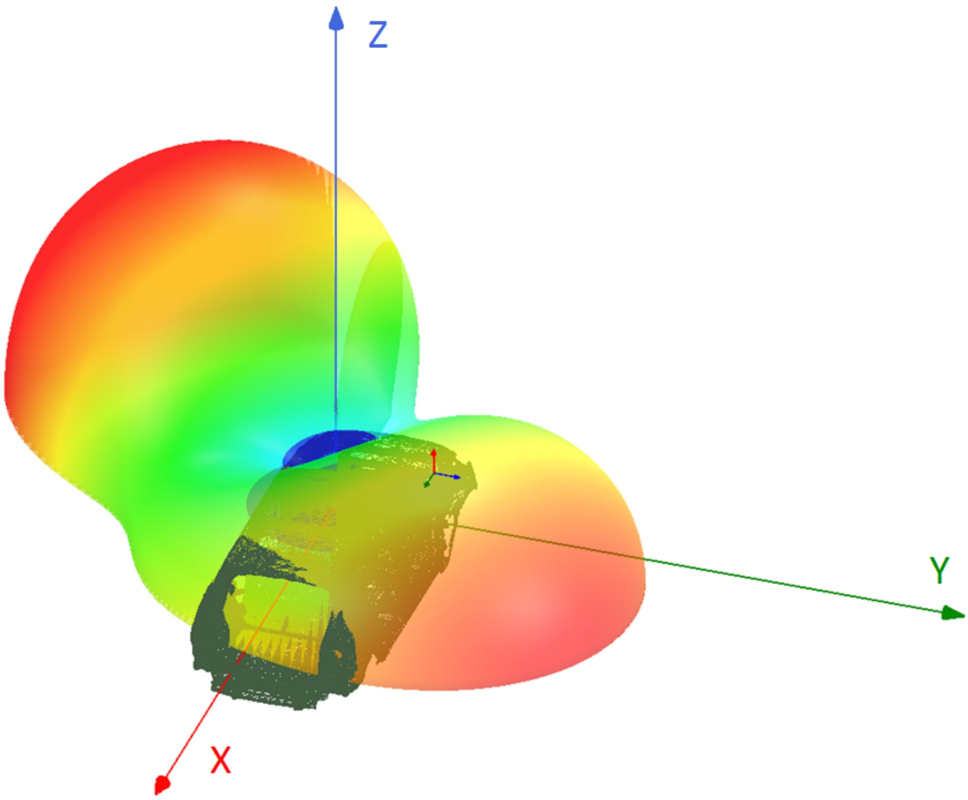

Development of EM Simulation Model for Vehicle Radiated Emission Test

Master's thesis in Wireless, Photonics and Space Engineering

FEIHONG OU

Department of Electrical Engineering
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2018

Master's thesis 2018:NN

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Cover: A brief view on the radiation pattern of a model in simulation

Typeset in LaTeX
Printed by [Name of printing company]
Gothenburg, Sweden 2018

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Abstract

Electrification is a main trend in the automotive development. This results in more EMC considerations during the vehicle design. In this report, a simulation method is proposed for simulating radiated emission from a component installed in a car body.

CAD cleaning and pre-processing are bottle necks when performing simulations in automotive industry. This project is aimed to find synergy effect by using the geometry with CAD cleaning already performed for mechanical simulation and modify it for EM simulation.

A study based on a simplified model consisting of a wire and sheets is first performed to check the influence of different ways to connect sheets on radiation properties. It is found that the modeling of electrical connection between the sheets is essential for EM radiation.

After that, several techniques to ensure electrical connection between the sheets are investigated. Two techniques of connecting sheets are further studied to understand the computational complexity and possible results.

This project has established a feasible method to process vehicle geometry for EM simulation regarding radiated emission in low frequency range. It is an initial but significant step for further investigation on the EMC performance in the automotive industry.

Keywords: EMC, Radiated emission, AM frequency range, Vehicle, Antenna, EM simulation, Pre-process, HFSS, ANSA, Methodology

Acknowledgements

During the whole thesis project, my supervisors and examiner have given me a lot of help. First I would like to thank my supervisor at CEVT, Robert Moestam, for his detailed guidance throughout the several months. And I do appreciate my supervisor at Provinn AB, Jan Carlsson, for sharing his valuable relevant experience with us. Of course my examiner, Jian Yang, owes my gratitude for his considerate administration and understanding.

I also want to take this opportunity to thank the kind people at Chalmers and CEVT for making this thesis project feasible. Without the permission from my program director, Lars Ulander, as well as my team manager, Sofia Ore, I would never have the chance to perform this exciting work. And the support from my colleagues both inside and outside the CAE department is quite impressive.

I am grateful for all the assistance and encouragement I got in this period. These contributions are of great help to my success in this thesis work.

Feihong Ou, Gothenburg, September 2018

Contents

List of Figures

List of Tables

1
Introduction

1.1 Background

1.1.1 Industrial Trend

Nowadays, as the automotive industry develops, electric components are more and more applied in vehicles. This trend is also called electrification. On one hand, electricity is applied as a main energy source for the sustainability purpose. And this leads to a wider promotion of modern electric vehicles such as Hybrid Electric Vehicle (HEV), Plug-in Hybrid Electric Vehicle (PHEV) and Battery Electric Vehicle (BEV). On the other hand, the rapid increasing demands on active safety, autonomous drive and infotainment involve more electronic devices on board. These electric parts do help improve the function of vehicle, but they can also cause problems due to interfaces. Therefore, electromagnetic compatibility (EMC) is an essential consideration for the development of vehicles.

1.1.2 Specification of EMC Investigation

EMC can be defined as the ability of an electronic system to function properly in its intended electromagnetic environment, and to not contribute interference to other systems in the environment [1].

In order to analyze the EMC relevant performance clearly, I used two classification criteria. One is the radiated path and the conducted path, and the other one is the emission and the immunity [2]. Therefore, the EMC research on vehicles can be divided into 4 types as shown in Figure 1.1. The main difference between the radiated path and the conducted path is the coupling mechanism. The former one is a wireless transmission way in form of EM field while the later one is the current coupling between two ports. For the definition of emission and immunity, they are just expressions of one phenomenon from opposite views. Emission talks about the influence from the interested sources on other parts, and immunity refers to the effects of relevant sources on the interested receivers.

In this project, the aimed investigation part is the radiated emission performance of the vehicle in a relatively low frequency band, i.e. in Amplitude Modulation (AM) range.

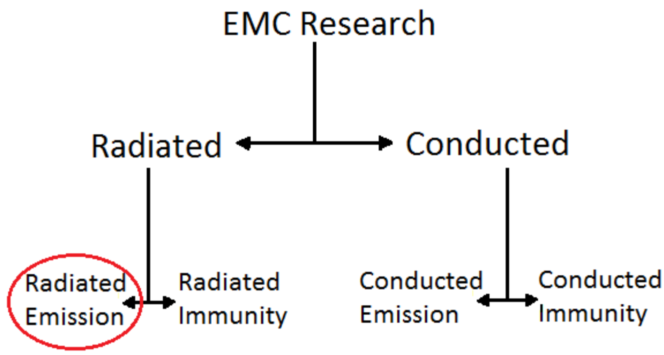

Figure 1.1: Classification of EMC Investigation on Vehicles

1.1.3 Radiated Emission Tests

As a main aspect of EMC research on vehicles, radiated emission tests have already been standardized according to international regulations such as CISPR 25. CISPR 25 is an international technical standard regarding the radio disturbance characteristics.

According to the example test set-up shown in Figure 1.2 [3], the antenna used for reception of radiated signals should be located on the vehicle. But the antenna can both be the external antenna or the ob-board antenna. Therefore, in order to minimize the test complexity, the on-board antenna is preferably used as the receiver to investigate the influence from on-board sources. For example, the AM antenna located on the rear window of a car can be used for the measurement of radio reception in the AM frequency range.

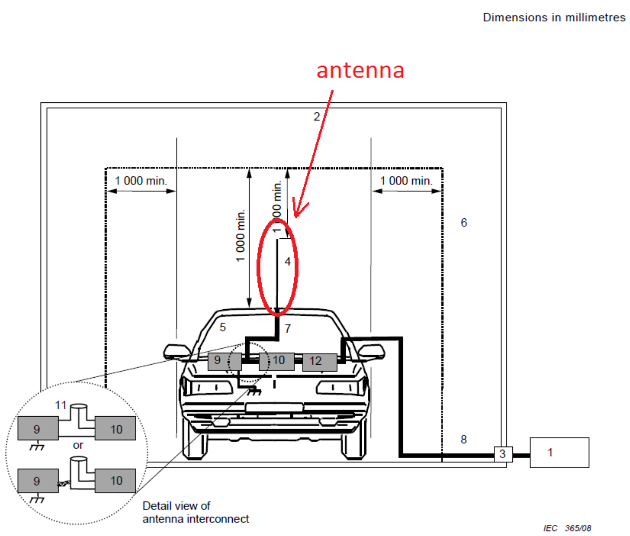

Figure 1.2: Example of Vehicle Radiated Emission Test Layout

1.1.4 EM Simulation of Vehicles

As an efficient way of investigating EMC performance, EM simulation serves an important compliment to EMC tests on vehicles. A suitable simulation can provide an initial overview on the interested areas with a relatively low expense. For the problems relevant to EMC, commercial electromagnetic (EM) simulation software is needed to analyze the automobile. This kind of simulation is also called Computational Electromagnetics (CEM).

Since the vehicle geometry is highly complex, the CAD cleaning and pre-processing of geometry model are crucial difficulties for performing EM simulation. Therefore, to obtain a feasible model of vehicle especially for EM simulation use is extremely important. Thus, the investigation of the method of making it is necessary.

1.1.5 Comparison of Different Numerical Methods for Simulation

There exist quite a lot of numerical methods for CEM [4] [5]. Among them, the most commonly used ones are Finite Difference Time Domain Method (FDTD), Finite Integration Technique (FIT), Finite Element Method (FEM) and Method of Moments (MoM).

FDTD is based on central-difference approximations and uses cubes as the basic elements. It has an advantage of flexibility and working on parallel computers. But the accuracy of the simulation results is very sensitive to the size of elements, so the amount of element will be huge if handling small details inside a relatively large volume. Thus this method is not suitable for models with very fine geometry details.

FIT is quite similar to FDTD in the way of treating equations, but it has a higher geometric modeling flexibility since the basic elements can be cut instead of the stable cube shape for FDTD case. It also has an advantage in the boundary handling part. But this method is not good at dealing with the model resulting in huge data amount as well.

FEM has its original use as a solution way of differential equations with specific boundary conditions. It is good at handling large objects with small details if all the boundaries are correctly defined.

Different from the three differential solutions, MoM is a powerful integral technique which can solve a wide range of mathematics equations including differential equations as well as integral equations. And it is widely used for Maxwell's equation. However, it will create dense matrix during the calculation which means this method has a higher demand of memory.

Since all these simulation methods have their own advantages, several kinds of commercial simulation software are developed originating from one of them. For example, Remcom Xfdtd runs simulation with FDTD solver, CST Microwave Studio is based on FIT at the beginning, Ansys HFSS mainly applies FEM for solution, and Altair FEKO is a simulation tool using MoM mostly [6]. A simple comparison of the 4 methods with representative software is shown in Table 1.1. Of course, these software tools have combined more numerical methods for optimization during the further development. But the initial method for implement is still the highlight of the corresponding tool.

In order to choose the most suitable simulation software for our case, some former relevant research reports are studied. By comparing the conditions and simulation results, FEM fits the need of keeping geometry details best. The main reason for this choice is that the vehicle geometry to be used in this project contains a lot of relatively small parts compared to the size of the car body. Therefore, HFSS is selected for this simulation model.

Table 1.1: Comparison of 4 Numerical Methods

Method	Advantage	Disadvantage	Software
FDTD	Working in parallel	Not suitable for fine details	Xfdtd
FIT	Higher model flexibility	Not efficient for complex models	CST
FEM	Good for combined geometries	Need boundary conditions	HFSS
MoM	Solvable for wide equations	Creating dense matrix	FEKO

1.1.6 Geometry Parts Included in Simulation Model

In order to simulate with possibly high accuracy in acceptable complexity, it is important to merely include critical components in this car model [7]. Since the AM frequency range is under consideration in this project, the AM antenna which takes the main radio reception in that frequency range should be included into the simulation model for radiated emission test. The radiation sources are from the on-board power electronics. The battery, cable harness, electronic control units (ECU) and motors are possible radiation sources. In this project, an ECU located in the EPAS in the engine bay of vehicle is selected as an example of potential source. Because the shielding is mainly due to reflection for low frequencies [8] [9], the shell of car and the engine as well as the electric power assisted steering (EPAS) close to that ECU have a great impact on EM field around vehicle. The model used in this project should be composed by these parts at least.

1.2 Scope

In order to ensure the proper function of a vehicle, EMC tests are done for both the components and the whole system before the mass production. However, these tests are rather expensive and time-consuming. Thus the implement of computer-aided engineering (CAE) is a good option as a prior assistance. The simulation results can point out possible problems at the design stage of product development. Based on these results, the engineers can review and modify the corresponding models before manufacturing them. And with the prediction of software simulation results, developers can focus more on these probable problem parts in the verification tests at the next stage.

In this project, a feasible procedure for creating a model for EM simulation use is proposed. And the method is simply verified by simulating on a pre-processed model as an example. To establish this method, a set of steps have been taken. First, a model representing the cable and shell is studied under different consequences to identify the acceptable simplification of the internal connection of car body. Then, a model of the vehicle under consideration is obtained for simulation making use of the computer-aided design (CAD) model with the necessary connections. After that, the simulations are done by inserting selected components gradually into the car model. Finally, the simulation results are analyzed and a conclusion is drawn. In a word, this work is an initial step towards the setup of complete EMC simulation analysis for automotive industrial use.

2

Study of Simple Geometry Models

2.1 Purpose

Body In White (BIW) is an assembly with several components joint to the car body frame [10]. In common cases, the car body contains several layers of sheet with welding spots as internal connection. However, the shielding performance of vehicle may change based on the amount of these connections. In order to investigate the influence of the connection degree so that the model can be simplified by keeping only the essential welding spots, a simple model representing the combination of cable and car shell is studied based on the former research [11].

2.2 Simulation Setup and Results

The base line model consists of a plain sheet, a solid cylinder, a constant current source port and a resistance terminal as shown in Figure 2.1. The perfectly conducting sheet is the model of shell but without any thickness. The sheet is 500mm in width and 1000mm in length. The cylindrical perfect electric conductor is the representation of a wire, which is a simplified cable without any specific dielectric information. The length of the cylinder is 750mm. This wire is located 5mm above the sheet.

By adding the source and the load, this geometry models a closed circuit from battery along cable to the device with grounding in the vehicle. This is a typical situation inside vehicle. For example, a ECU is powered by a 12V battery with cable in between. The current goes from the battery to the ECU through cable. Both the battery and the ECU are grounded so the current can go further through the common grounding sheet.

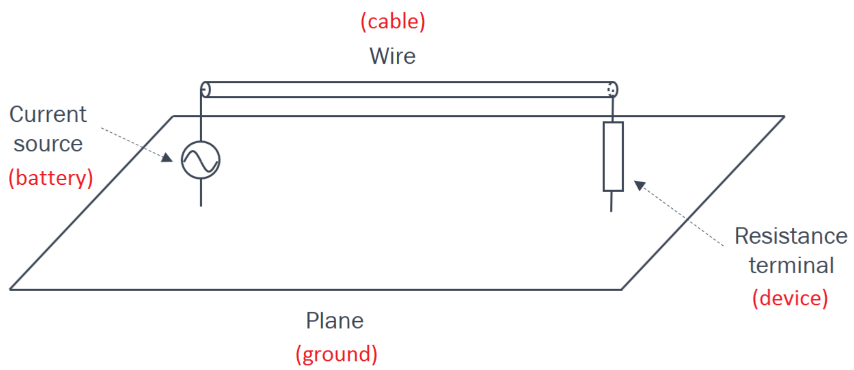

Figure 2.1: Model with Full Connection

Compared with a loop antenna as shown in Figure 2.2 [12], the whole model is a ground loop antenna with loss. It is radiated by excitation of the common mode current from the source port.

Figure 2.2: Loop Antenna

Since the aim is to evaluate the reduced shielding performance of different connection ways, the situations are classified into 3 main types. The first condition is the original model, which represents the completely connected case. The second one is just the opposite to the former case, which have two planes with a vertical gap in the overlapping part. The third condition is partial connection, just adding different amounts of welding spots in the gap.

2.2.1 Case 1: Complete Connection

In the initial case as Figure 2.1, there is only one plane which is equal to two fully connected sub-planes. In order to simplify the model, the value of the current from the excitation port is the default one, and the resistor at the other end of the wire is a matched one in common conditions. For the same reason, the material of the cylinder is set to be perfect conductor, and the boundary condition of the plane is a perfectly conducting surface in HFSS.

2.2.2 Case 2: No Connection

In this simulation case, the plane in the former model is changed to be two partly overlapping planes as shown in Figure 2.3. The vertical distance between them is 0.7mm, which is the common spacing between the sheets of car body. Similar to the settings of the former geometry, the two smaller planes are also perfectly conducting surfaces. The gap in between leads to disconnection, so the current from the source can hardly go through it at low frequency. By this theoretical analysis, the performance of it should be totally different from the former geometry.

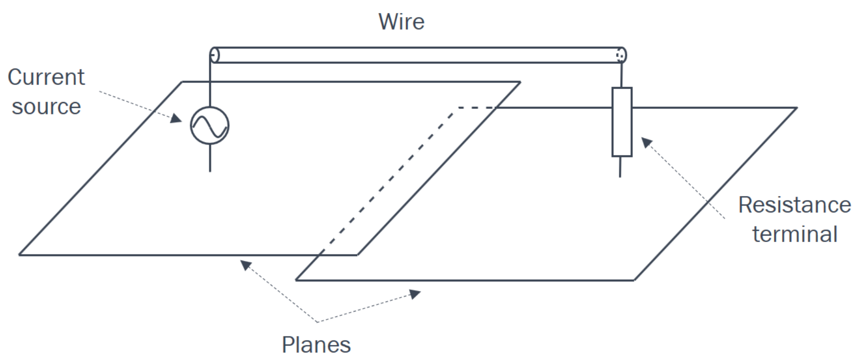

Figure 2.3: Model without Connection

2.2.3 Case 3: Partial Connection

For this case, welding spots are represented by small cylinders filling the gap between the two sheets. Three specific connection conditions are investigated as mentioned in the referenced work [11]: 2 welding spots, 4 welding spots and 6 welding spots. The corresponding models are shown in Figure 2.4, 2.5 and 2.6.

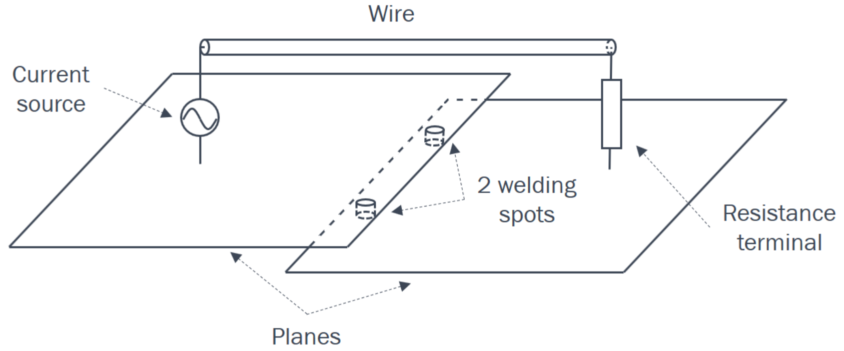

Figure 2.4: Model with 2 Welding Spots

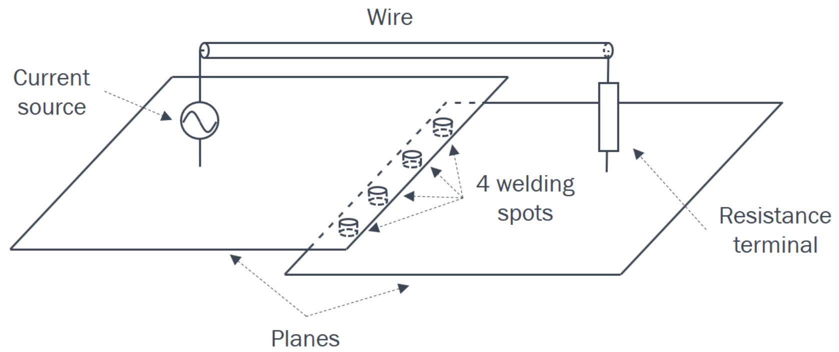

Figure 2.5: Model with 4 Welding Spots

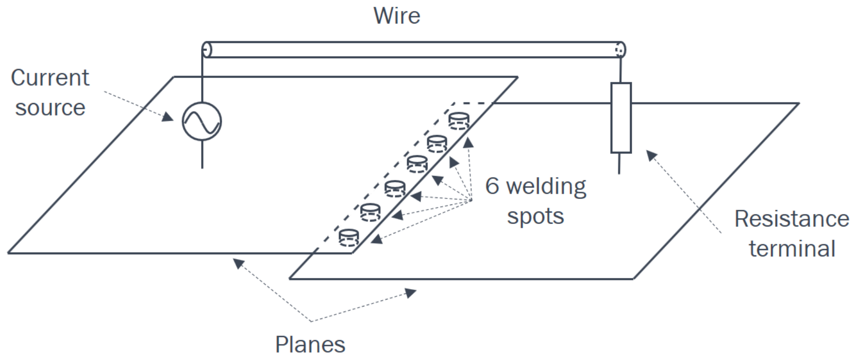

Figure 2.6: Model with 6 Welding Spots

2.2.4 Comparison of Results

By simulating the five established models described before, the influence of connection appears in the results. The integrated radiated electric field (E-field) is chosen as the parameter indicating EM field distribution of corresponding geometries. First, the simulation is run in the frequency range from 30MHz to 1GHz, which is the investigated range in the referenced report [11]. The difference of radiated E-field due to different connection ways is shown in Figure 2.7. According to these results, it is obvious that the values of radiated E-field for all these connection ways are similar to each other at higher frequencies. But the values of radiated E-field are quite different for models with or without connection at lower frequencies.

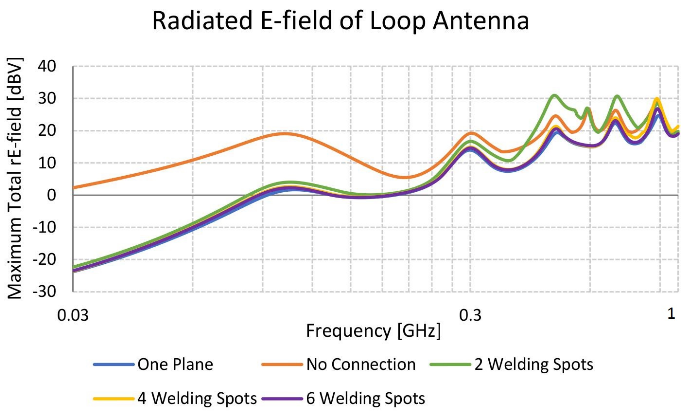

Figure 2.7: Integrated Radiated E-field Value of Different Connection Ways from 30MHz to 1GHz

Based on this observation, the five models are also simulated from 1MHz to 30MHz, which refers to the AM frequency range in this project. The simulation results are shown in Figure 2.8. From this plot, it is clear that the four models with connection have almost the same radiated E-field value while the model without any connection has a higher field value over the whole band.

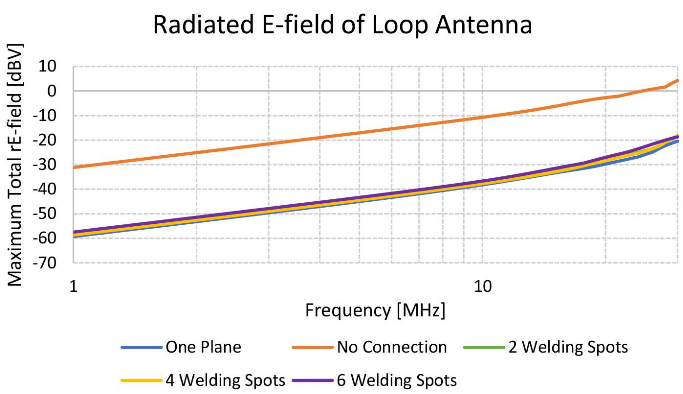

Figure 2.8: Integrated Radiated E-field Value of Different Connection Ways from 1MHz to 30MHz

2.3 Conclusion from the Simplified Models

Inspired by the former research [11], a series of models with simplified geometry are investigated by simulation. The only difference between these models is the connection way between the sheets. According to the comparison of radiated E-field values, the connection between sheets is necessary for keeping the EM field performance at low frequencies despite the sheets are connected fully or partly. And the amount of welding spots seems to have little influence on the result, indicating the model can contain fewer welding spots if using the partial connection way.

3

Process on Vehicle Geometry

Since the geometry of a vehicle is always complex with a lot of details, it is not efficient to take the most accurate model into simulation for primary investigations. The cost of time as well as the memory usage of computers are the fundamental considerations in this project. Therefore, a simplified geometry keeping the essential properties of vehicle must be created before starting EM simulation.

Based on the conclusion from the investigation in last chapter, the main composition of a vehicle, i.e. the car body with sheets, can be simplified on condition that it still keeps the internal connection. Therefore, two simplification directions are proposed in this report. One is for the partial connection, and the other one focuses on the full connection.

3.1 Investigation of Geometric Simplification

To utilize synergy effects between CAE departments, the starting point is a geometry model provided by structural dynamics team. It is a cleaned FE-model of the vehicle taken into account in this project. The pre-processor called ANSA is used to deal with the vehicle geometry. It is a commercial software provided by BETA CAE Systems. Because of the wide range of functions it has, it is popular in vehicle industry. Another software intended for geometry modeling used in this project is SpaceClaim from ANSYS Inc., which is also the owner of the EM simulation software HFSS. It is mainly used to check the output from ANSA before input the model into HFSS as it has a better compatibility with HFSS.

3.1.1 Model with Welding Spots

Output Model in CAD Format

The initial model without any modification is shown in Figure 3.1. It is just the so-called BIW. Since computer-aided design (CAD) file is the original format of geometry design, it should be easier to keep the model details in CAD format after simplification.

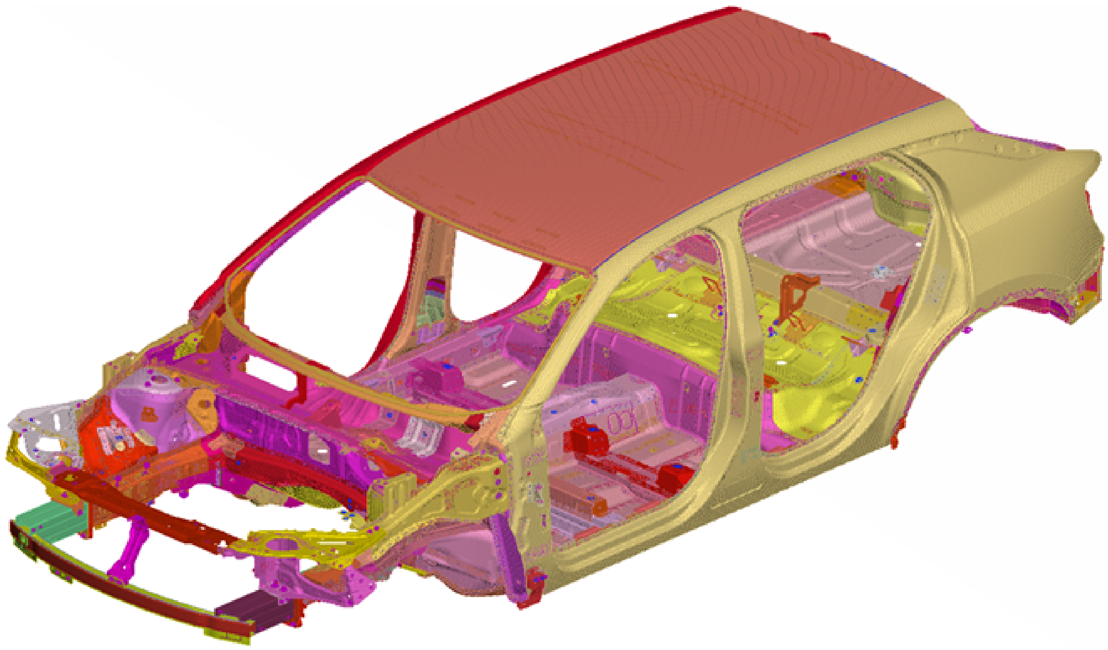

Figure 3.1: Original Model of Vehicle

The model in ANSA mainly consists of two parts, the sheets and the welding spots as shown in Figure 3.2 and 3.3 respectively. The sheets are FE-model sheets, which are based on the middle surfaces extracting from the 3D geometry of vehicle shell in reality. The welds are the representative symbols specifying the location of connections which can be changed into different forms.

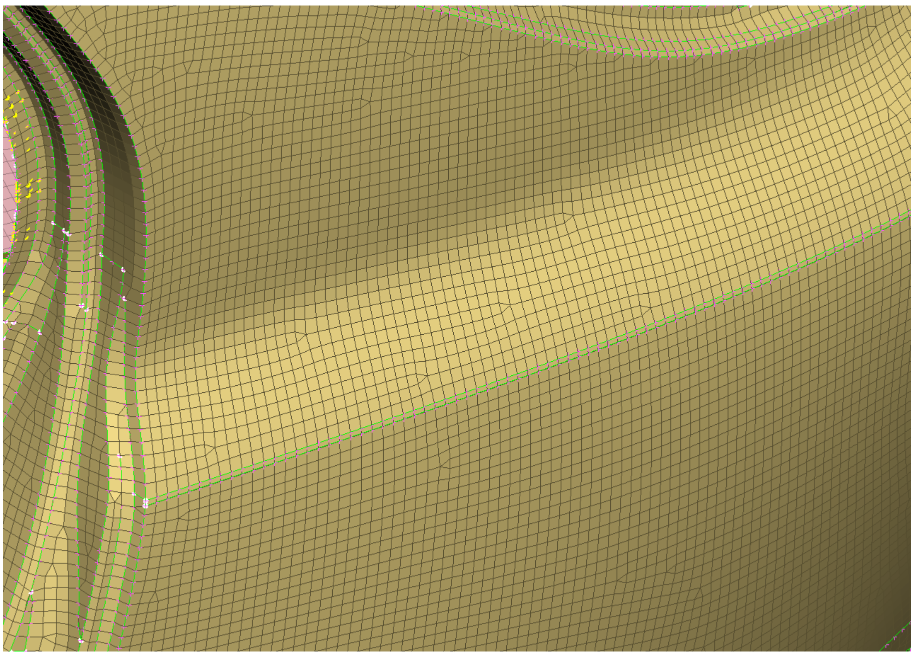

Figure 3.2: Sheet Representation

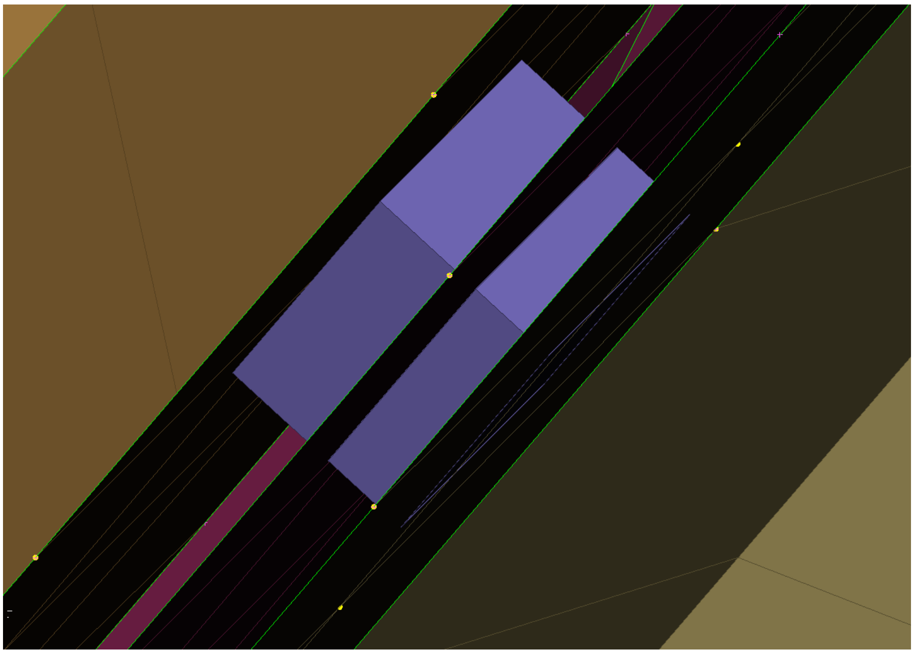

Figure 3.3: Welding Spot Representation

Based on the conclusion from the former chapter, the connection between sheets is reduced by maintaining only the necessary welding spots as shown in Figure 3.4. However, these welding spots seem to lose the electrical connection, which is needed for investigating the EM field distribution around the intended vehicle. The disconnection can be seen by checking the model in SpaceClaim as shown in Figure 3.5. It is obvious that the cube representing welding spot intersects with the orange sheet and the two surfaces are not merged as they should.

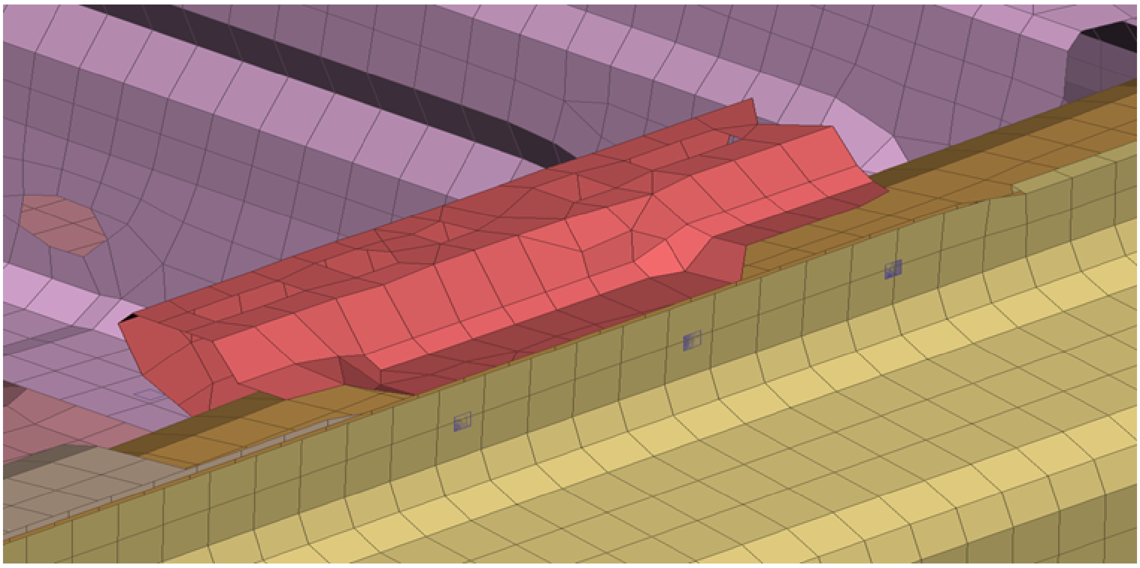

Figure 3.4: Welding Spots in Initial State

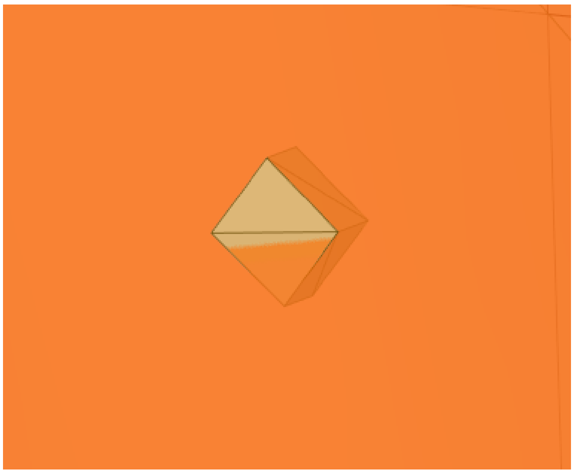

Figure 3.5: Check on Initial Welding Spots

A possible solution to this problem is to use 'Script' function in SpaceClaim. By inputting the center of a welding spot and its coordinate system, the expected connection is able to be reconstructed. However, it takes a lot of additional time to collect all the information from ANSA and to establish the commands in SpaceClaim. Thus the investigation is aborted in this project.

Another problem appearing in SpaceClaim is that the sheet splits into several pieces as shown in Figure 3.6. The disconnection leads to an increase in the complexity of geometry. Fortunately, this problem is fixed by using 'Stitch' function in SpaceClaim to close narrow gaps between the surface parts.

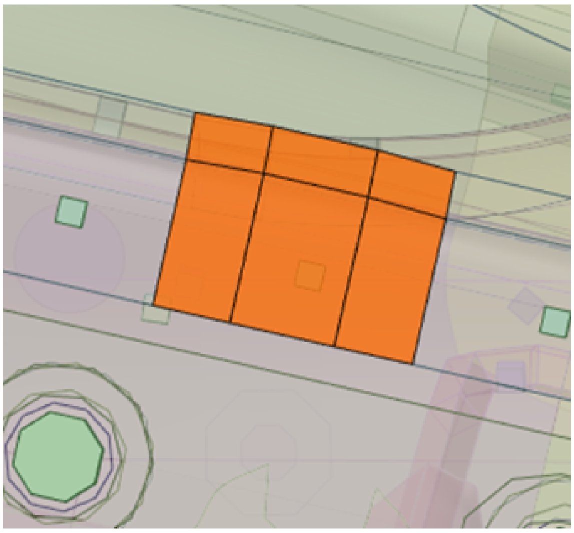

Figure 3.6: Separate Pieces of A Sheet

In a word, the model with welding spots in CAD format still needs to fix the electrical connection problem. A possible way to solve it is to do more scripting work in the future. Therefore, this model is not useful in this project.

Output Model in Mesh Format

Apart from the CAD format, output of mesh based on the geometry is also a good way to represent the connection. In order to keep valid electrical connection, the welding spots are changed in ANSA to reconstruct the surface mesh. After trying different types in ANSA, the most suitable one turns out to be the style called 'Spider2', which can mark the exact position of welding spots on the connected surface by making a hole there. By selecting the relevant options, the model type of welding spots is modified to be a suitable one and all the welding spots are electrically connected to sheets as shown in Figure 3.7. The operation took a couple of hours, which is acceptable in the project.

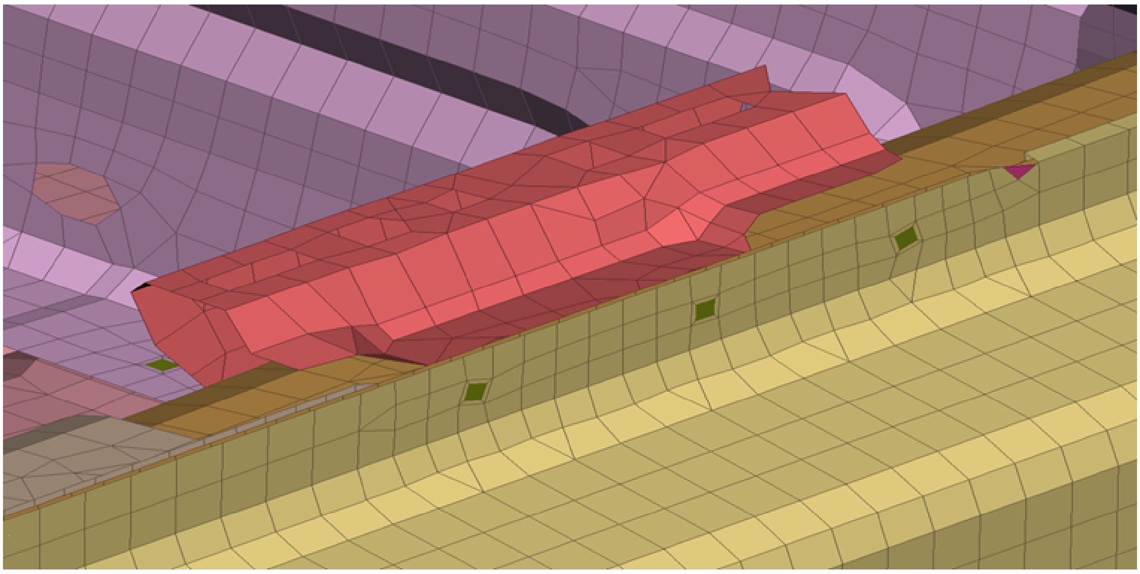

Figure 3.7: Modified Welding Spots

In order to further simplify the geometry for easier mesh, a function called 'Reduce' is applied after changing the type of welding spots in ANSA [13]. This operation changes the initial rectangular mesh elements into triangular ones, which can decrease the amount of elements by coarsening mesh as shown in Figure 3.8. And the electrical connection successfully remains in the new geometry as shown in Figure 3.9.

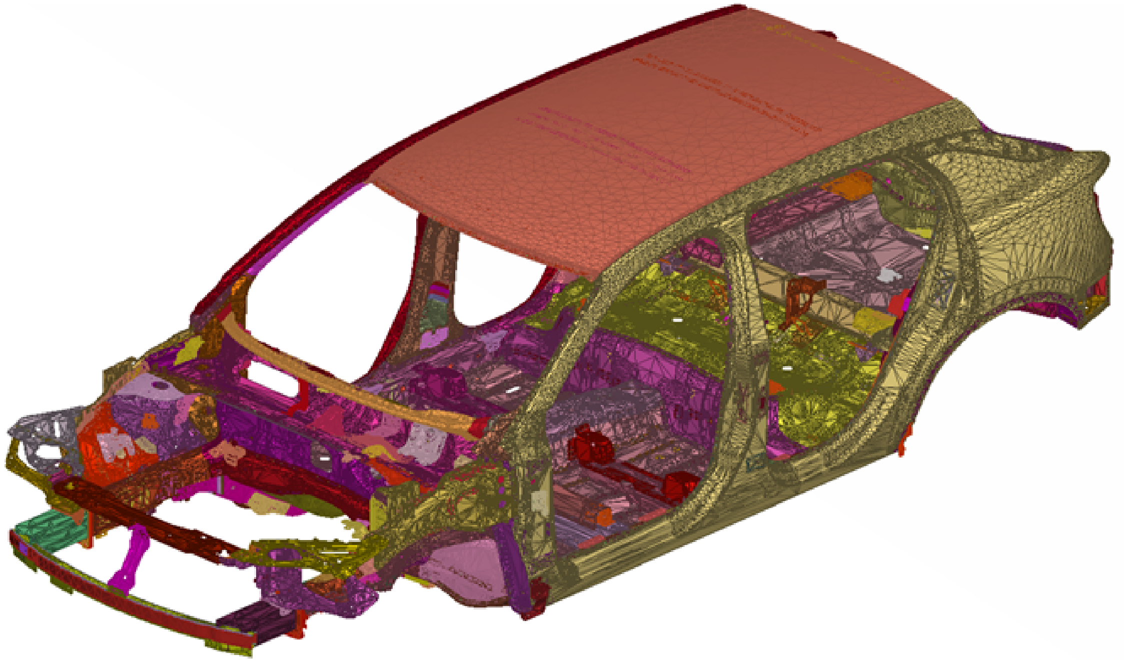

Figure 3.8: Model with Coarsened Mesh

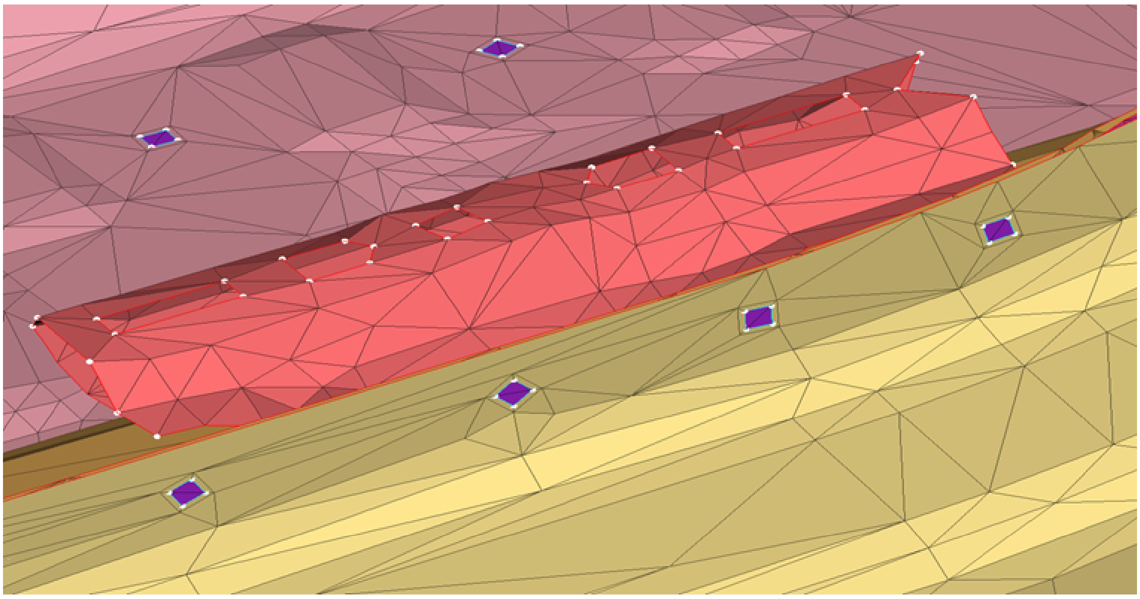

Figure 3.9: Welding Spots with Coarsened Mesh

Since the whole process to output the geometry based on mesh takes a much shorter time, it is a potential model to use in this project.

3.1.2 Model with Full Connection

Output Model in CAD Format

Same as the case with partial connection, the fully connected model is supposed to be output in CAD format at first. A possible way is to use a solid volume along the gap as shown in Figure 3.10. However, there is no available function which is robust enough to be used in ANSA right now. Therefore, this format is not used in this project.

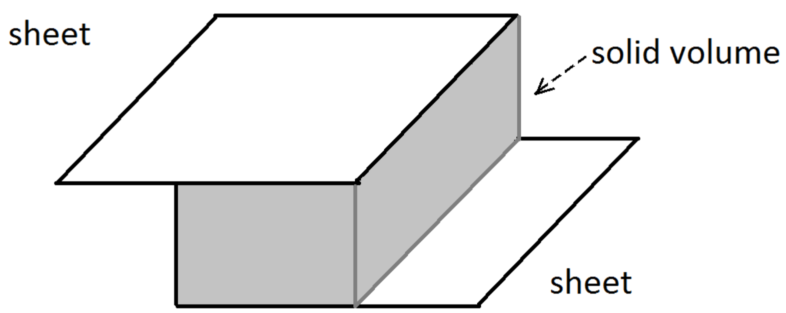

Figure 3.10: Possible Method to Close Gap

Output Model in Mesh Format

In order to obtain the fully connected model in a simpler way, the function called 'Wrap' is applied in ANSA [14]. This operation can connect two sheets by creating a closed surface covering them as shown in Figure 3.11. In this way, the two sheets are replaced by one bent sheet, which equals to the situation that they are fully connected.

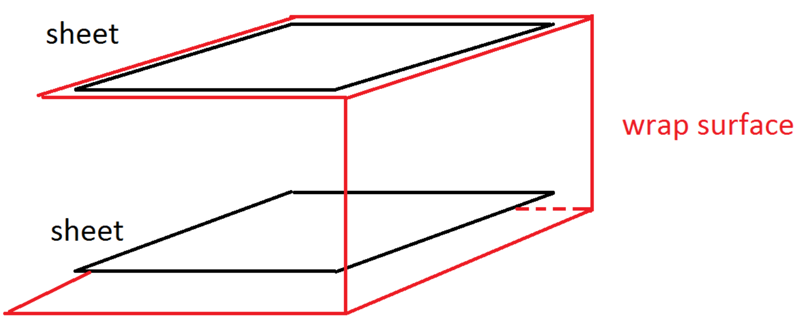

Figure 3.11: Wrapping Two Sheets

In order to access a model with suitable geometry complexity, the minimum length is set to be 30mm, and the feature angle uses the value of 20 degree. And to better close the gaps between sheets, an additional operation called 'Volumize' in ANSA is used [15]. The mechanism of this function is shown in Figure 3.12. By doing this, the gaps between the two-dimensional sheets can be easily closed since the parallel planes exist when wrapping the model.

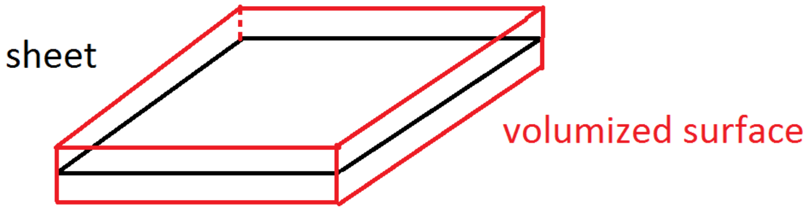

Figure 3.12: Volumizing A Sheet

Based on the two useful functions in ANSA, it takes around 10 hours to obtain the final model with wrapped surface as shown in Figure 3.13. The mesh in this model is relatively coarse with fewer geometry details compared to the original model. But the most important part, electrical connection, is kept in this model. Thus it is also under consideration for simulation use.

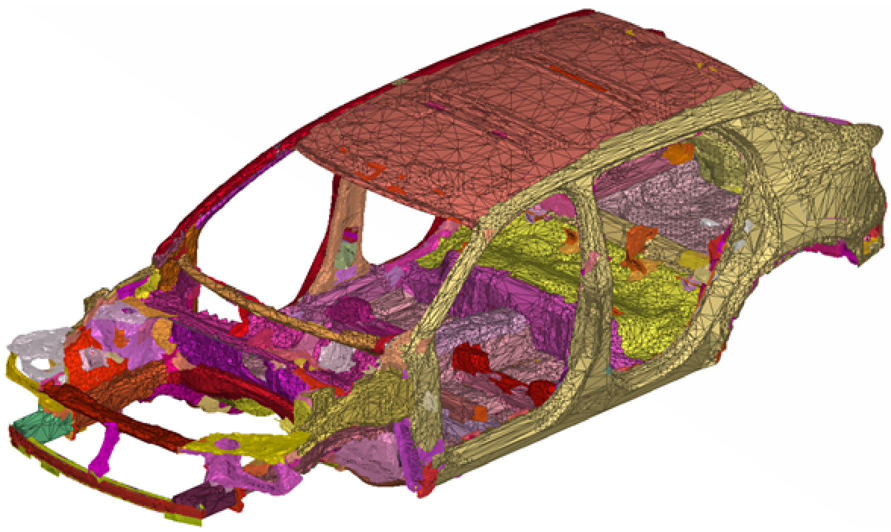

Figure 3.13: Model with Wrapped Surface

3.2 Comparison between Mesh Results of 2 Feasible Models

In order to optimize for simulation use, the mesh of model should be suitable both in quality and quantity. For this reason, the original model which takes more than 4 days for initial mesh is not feasible for this project. Therefore, the two obtained models with partial and total connection are initially meshed in HFSS to examine the performance as shown in Figure 3.14 and 3.15. Due to the difference between software environments, the two models in STL format are input losing the properties of individual parts of the vehicle.

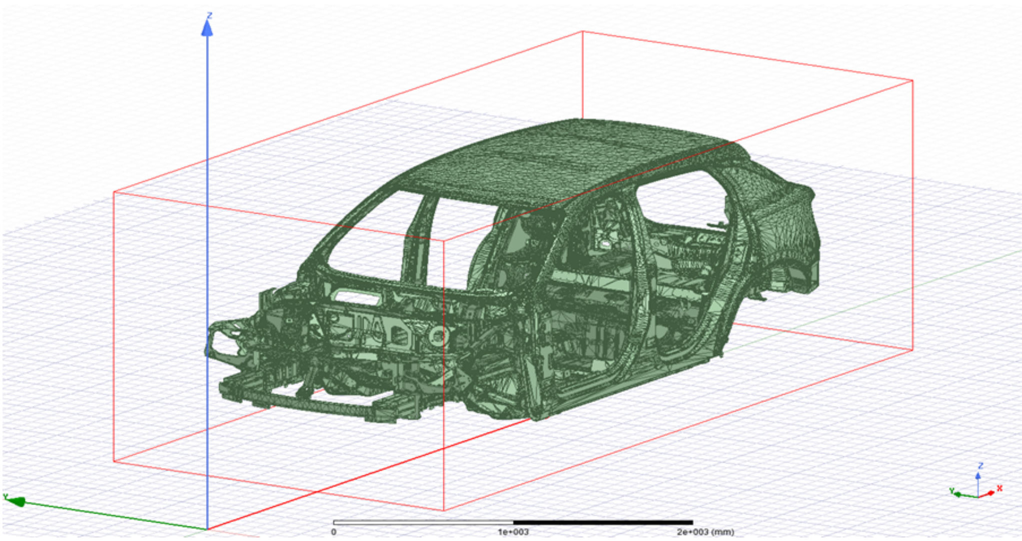

Figure 3.14: BIW with Partly Connected Sheets

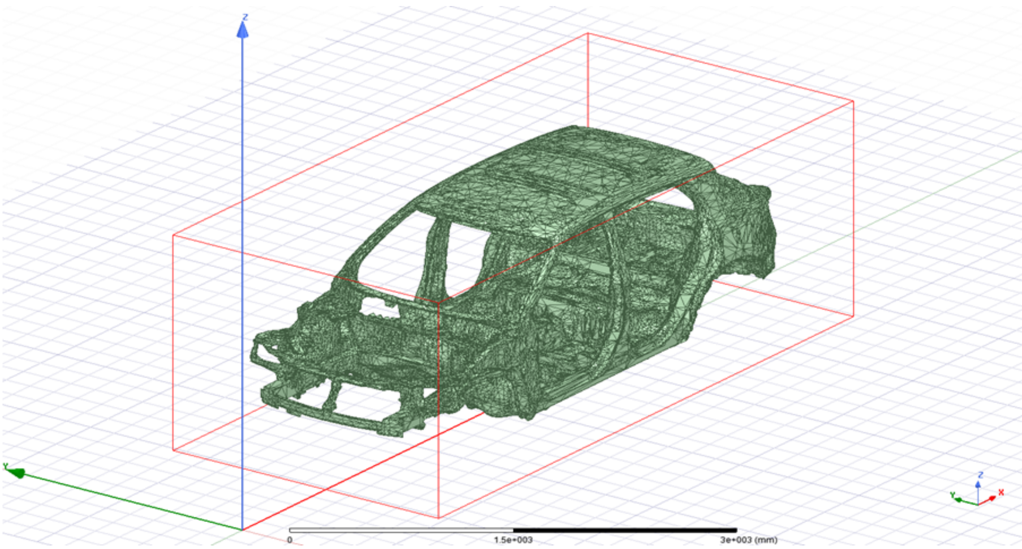

Figure 3.15: BIW with Fully Connected Sheets

Since the models contain a large amount of data, High Performance Computing (HPC) is enabled in the mesh operation [16]. To specify, both the models are meshed with 20 cores and have a RAM limit of 90% as the limitation of memory usage [17].

The mesh results are shown in Table 3.1. According to the comparison between mesh results of the two models, the model with full connection in geometry has a great advantage over the other one due to the less time consumption and memory usage. The main reason for this lower computational complexity is that this model is much coarser than the other one.

Table 3.1: Comparison of Mesh on 2 Models

Model	Element Amount	Real Time	CPU Time
Partial Connection	2,885,743	15:54:44	138:14:48
Full Connection	622,116	00:36:04	03:34:44

3.3 Conclusion

A method for vehicle geometry simplification aimed at simulation application is proposed in this chapter. Starting from the geometry file provided by structural dynamics department, both partial and full connection cases are studied. Two types of output models are investigated, but only the model in mesh format is feasible at this stage. Although the model with welding spots contains the connection way closer to the reality, the model with wrapped sheets is better in terms of mesh performance. Since the mesh demand is important for simulation in HFSS, the model with fully connected sheets is the preferred way.

4

EM Simulation on Vehicle Model

In order to examine the feasibility of the proposed pre-process method, the model after wrapping is investigated in HFSS. The idea of setting up a simplified simulation model to study EMC in HFSS is generated from the model as shown in Figure 4.1 [18]. Since the radiated emission is mainly affected by the reflection at low frequency, the metal surface is the investigation focus. Therefore, apart from the source and receiving part, the car body, engine and EPAS are also included in the simulation model step by step.

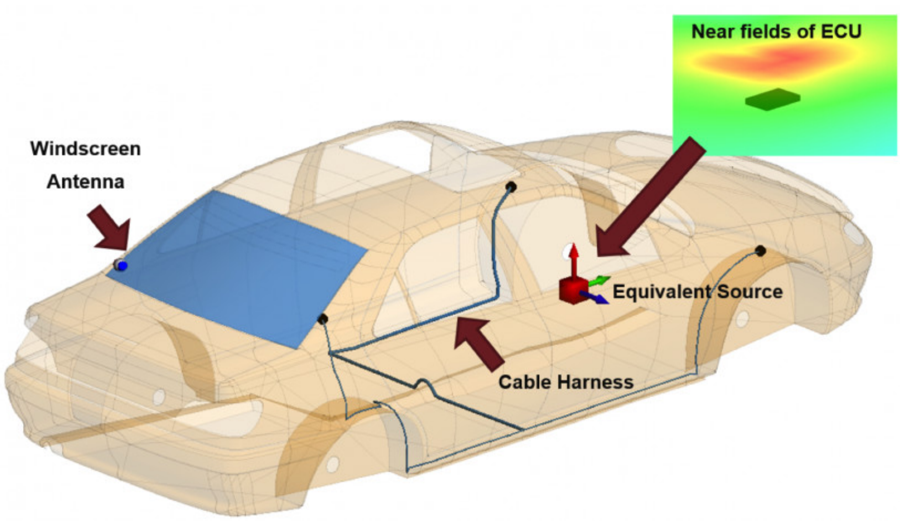

Figure 4.1: Model for EMC Simulation in HFSS

For the source in the simulation model, a dipole antenna is used as a typical radiating source inside vehicle. For the receiving part, only the EM field at the corresponding position is studied. Therefore, no actual receiver is placed for AM reception.

Due to these simplification, it is a kind of general model for simulation use which cannot provide an accurate result. But as for the validation purpose, this robust geometry is sufficient.

4.1 Different Dipole Orientations

Since polarization is a significant factor in the transmission of EM waves from the transmitting antenna to the receiving antenna[19], three typical placements of dipole antenna in an orthogonal coordinate system are studied by simulation as shown in Figure 4.2. The dipole antenna is placed along z-axis, y-axis and x-axis individually. In the simulations, the length of this dipole antenna is around 160mm, which is close to the size of ECU.

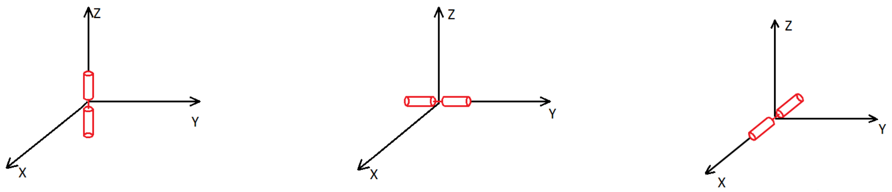

Figure 4.2: Three Alignment Types of Dipole Antenna

4.2 Compromise in Simulation Settings

Because the simulation is for the radiated emission investigation in low frequency range, the simulation domain in HFSS is very large based on the wavelength to ensure the correct radiation boundary. Therefore, it is not efficient to use the default mesh setting. Since the radiated field around vehicle is the focused part in this project, an optional mesh refinement setting is used to make the most of computational resource [20]. By splitting the simulation region into two parts, the small volume covering the vehicle has a much denser mesh as shown in Figure 4.3. The magnified view is shown in Figure 4.4. The area marked by yellow circle is the position of the dipole antenna, and the area inside the green circle is the position of AM antenna on the rear window. The inner region is meshed with elements whose maximum length is 100mm, which is comparable to the small details of the vehicle geometry. By doing this, the mesh takes much shorter time and less memory resulting in an affordable simulation.

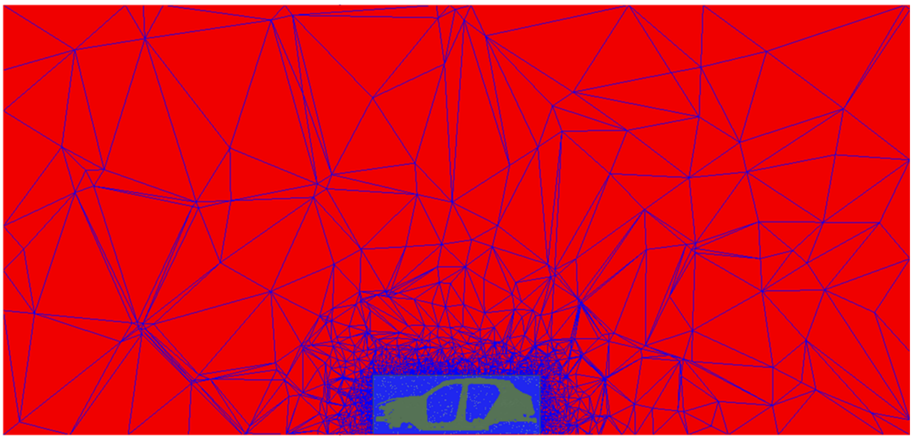

Figure 4.3: Divided Mesh Regions of Model

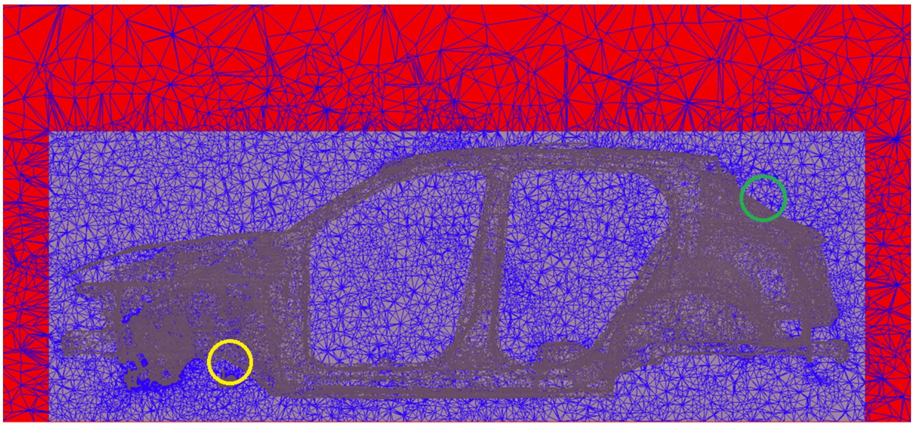

Figure 4.4: Region around Vehicle with Denser Mesh

4.3 Models Used in HFSS

To investigate the influence of different parts on radiated emission performance of vehicle, the selected components are added into the simulation model gradually. First, the performance of the dipole antenna is studied by simulating it in the 3 defined states. Then, the 3 models include the wrapped car body separately. Last, the 3 models contain the engine and EPAS into simulation.

4.3.1 Case 1: Antenna

The dipole antenna is located at a certain position in the defined region as shown in Figure 4.5. For all the 3 placements, the dipole antenna is centered at the position of ECU inside the engine bay in the front of vehicle, which is the same for the following models including more components.

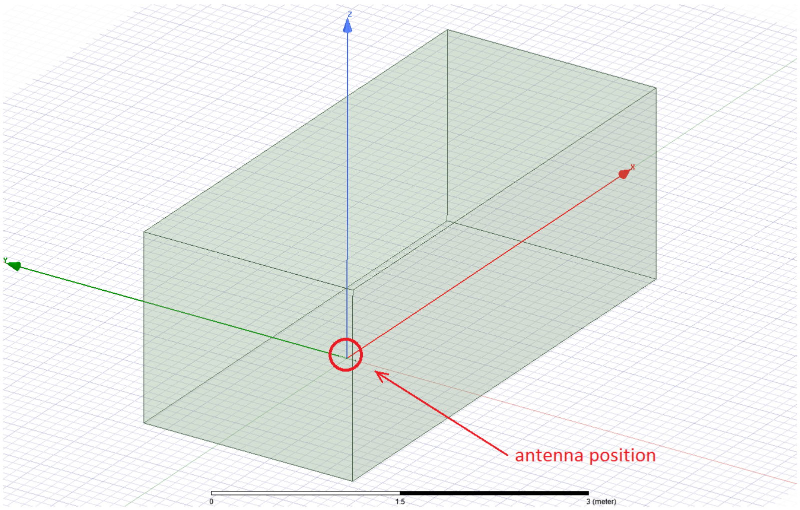

Figure 4.5: Antenna Simulated in the Fixed Region

4.3.2 Case 2: Antenna, Wrapped Car Body

In order to be closer to the real condition, the car body geometry investigated in the former chapter is modified by adding the hood and fender around the engine room. Since it is a very slight change, the complexity of the model keeps almost the same as before. The model input into HFSS for simulation is shown in Figure 4.6. The 3 corresponding models is represented by one figure here since the only difference between them is the placement of dipole antenna.

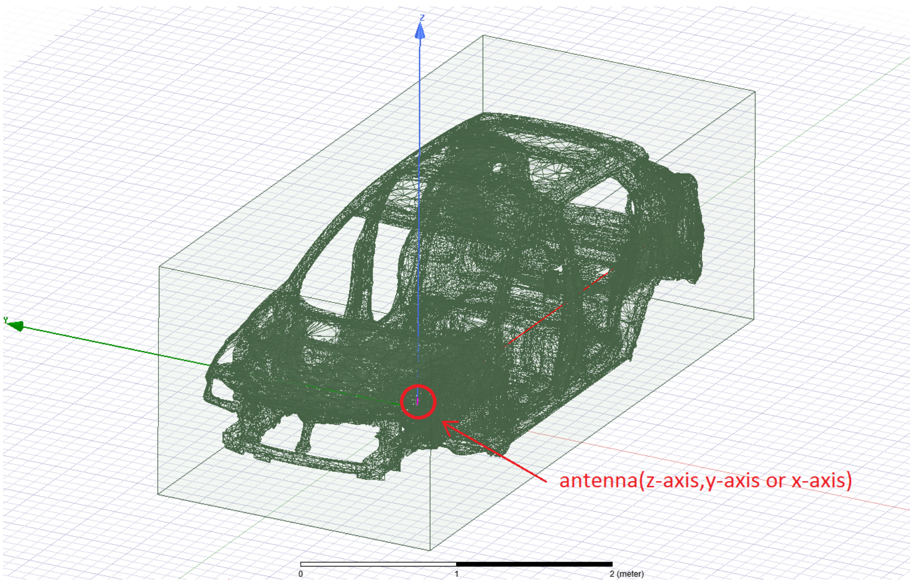

Figure 4.6: Model with Antenna and Car Body

4.3.3 Case 3: Antenna, Wrapped Car Body, Engine and EPAS

Based on the model from Case 2, the important components as the engine and EPAS are added into the model as shown in Figure 4.7. The purple part is the two components located under the hood. Same as the former case, it is also representative in terms of different states of dipole antenna.

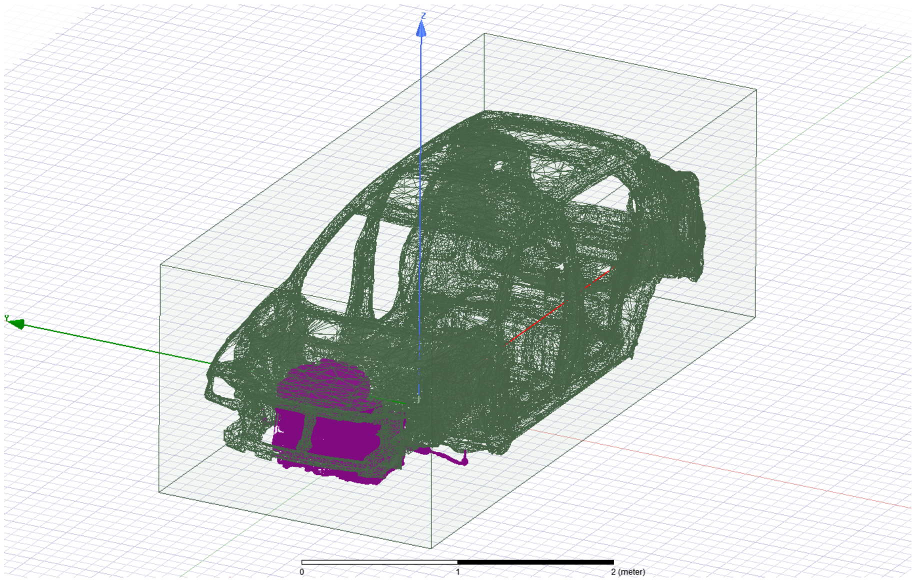

Figure 4.7: Model with Antenna, Car Body, Engine and EPAS

5

Results

After setting up and running the simulation models in HFSS, the result of E-field distribution and radiation pattern of corresponding model can be obtained. The E-field is plotted on the plane cross the center of source antenna as shown in Figure 5.1. The place marked with a pink circle is the dipole antenna position. The part in the orange circle is the AM antenna location, and the AM antenna position is also pointed out with red circles in all the following plots of E-field.

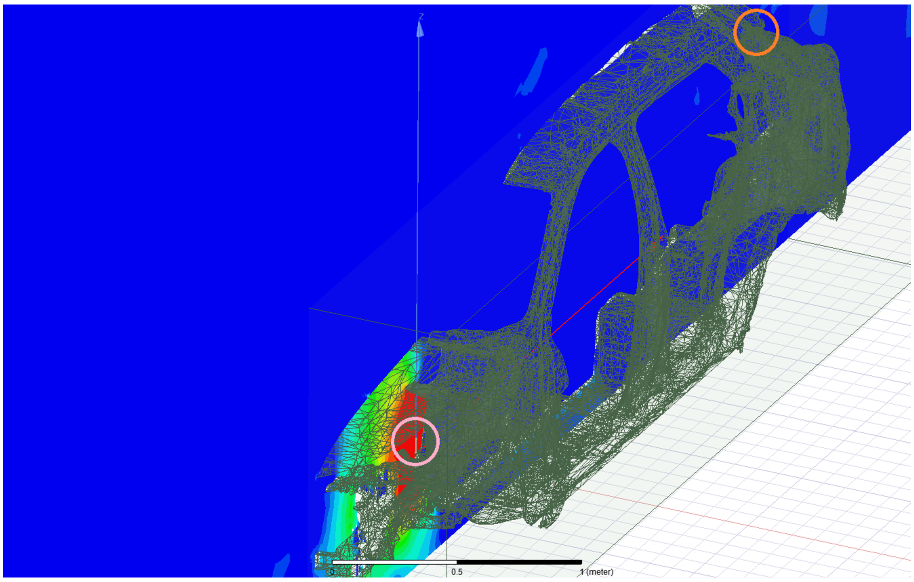

Figure 5.1: Plot Plane Location

5.1 Simulation Results of Former Models

5.1.1 Results of Antenna

The E-field around the antennas are shown in Figure 5.2, 5.3 and 5.4 as for the 3 placements of dipole antenna.

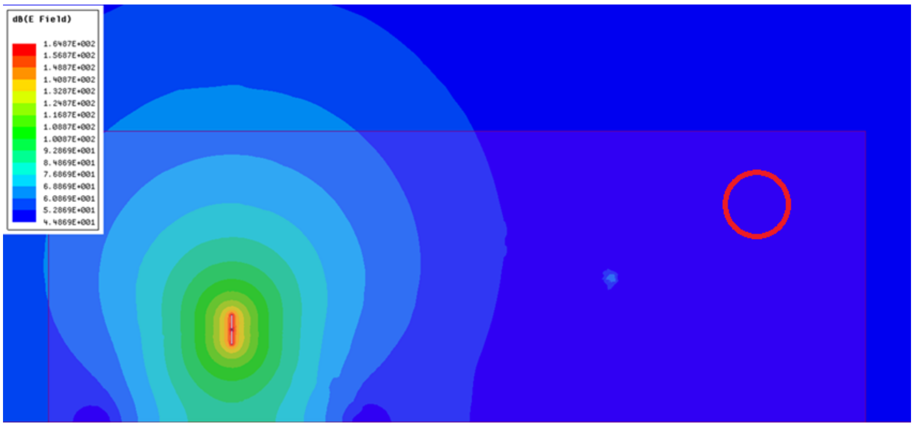

Figure 5.2: E-field around Antenna along z-axis

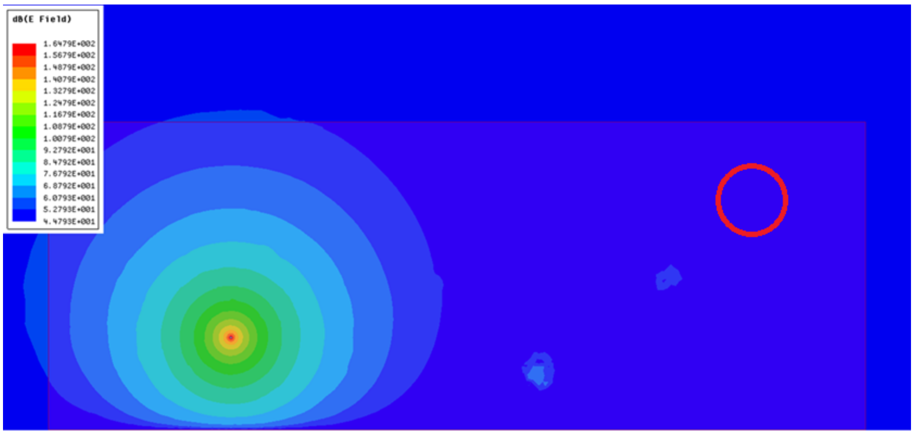

Figure 5.3: E-field around Antenna along y-axis

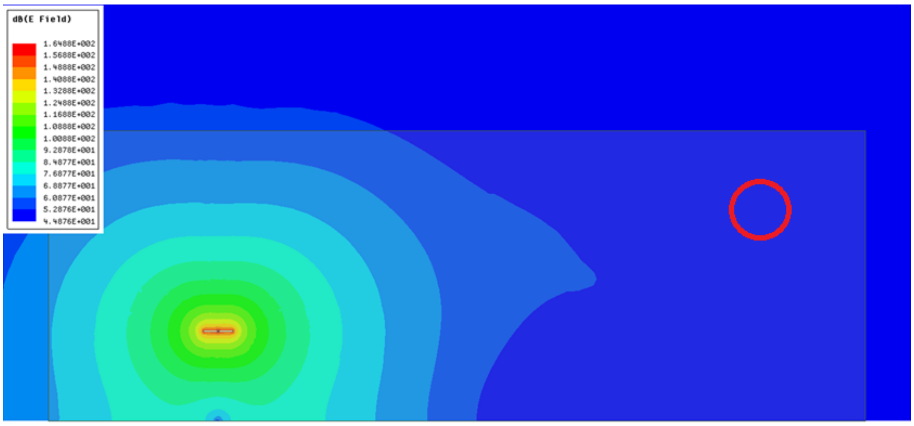

Figure 5.4: E-field around Antenna along x-axis

5.1.2 Results of Antenna and Wrapped Car Body

The E-field of the combination of dipole antenna and wrapped car body is shown in Figure 5.5, 5.6 and 5.7 for dipole antenna located along z-axis, y-axis and x-axis separately.

Figure 5.5: E-field with Antenna along z-axis

Figure 5.6: E-field with Antenna along y-axis

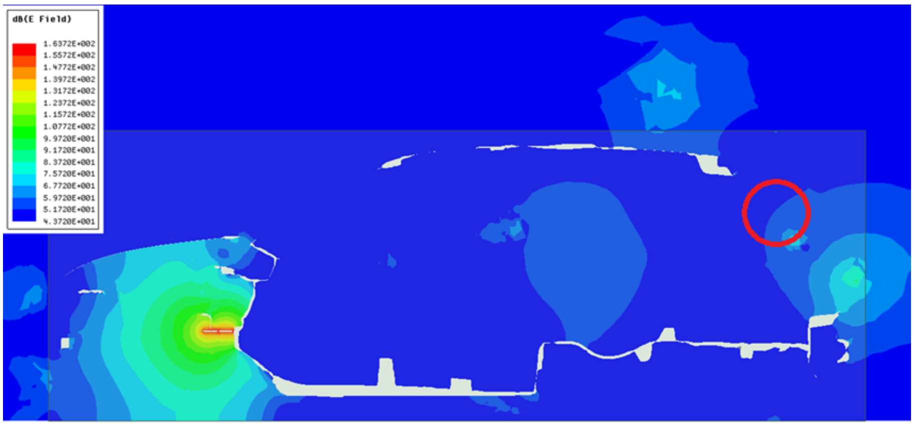

Figure 5.7: E-field with Antenna along x-axis

5.1.3 Results of Antenna, Wrapped Car Body, Engine and EPAS

The results of E-field for the 3 models with antenna, car body and the two components are illustrated in Figure 5.8, 5.9 and 5.10.

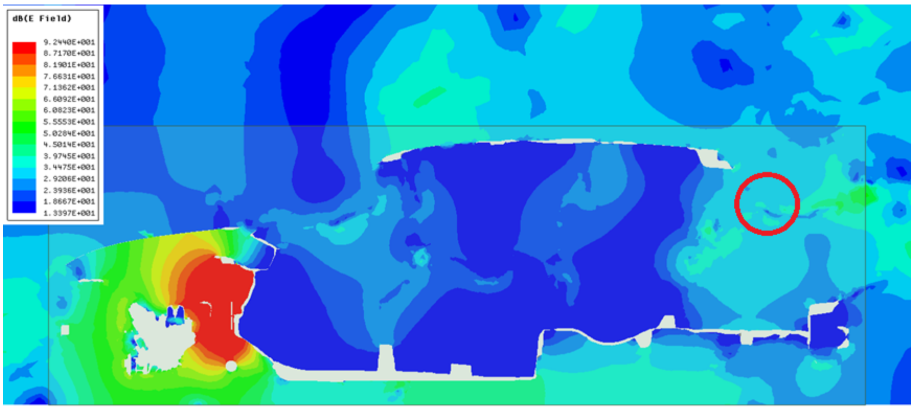

Figure 5.8: E-field with Antenna along z-axis

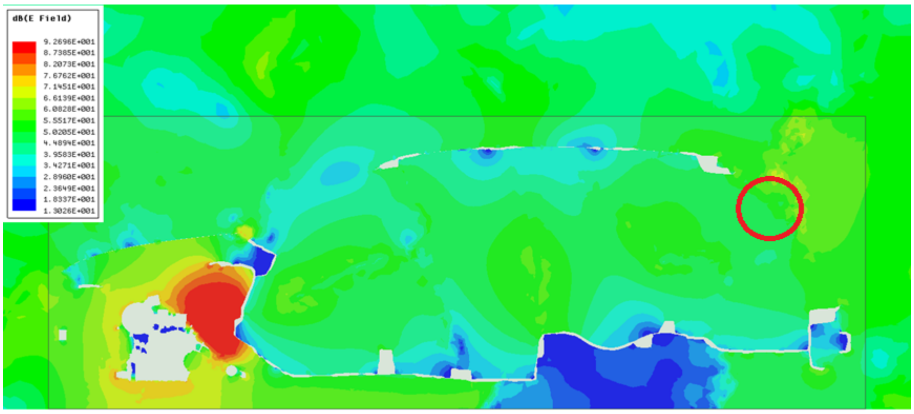

Figure 5.9: E-field with Antenna along y-axis

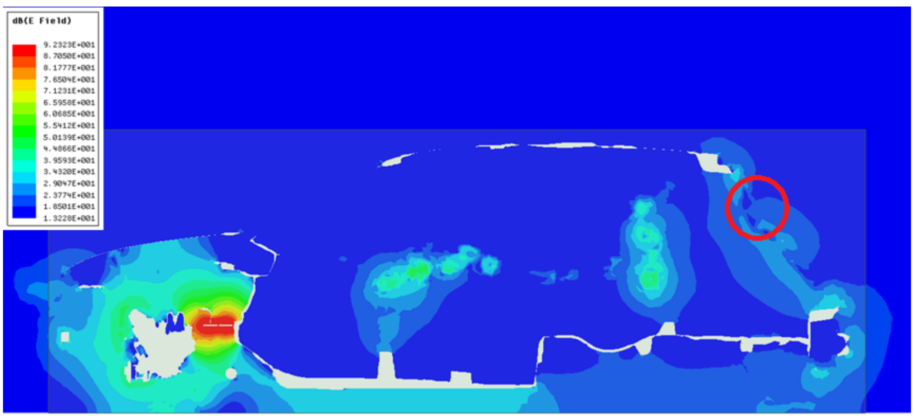

Figure 5.10: E-field with Antenna along x-axis

The radiation pattern are also plotted for the 3 models as shown in Figure 5.11, 5.12 and 5.13.

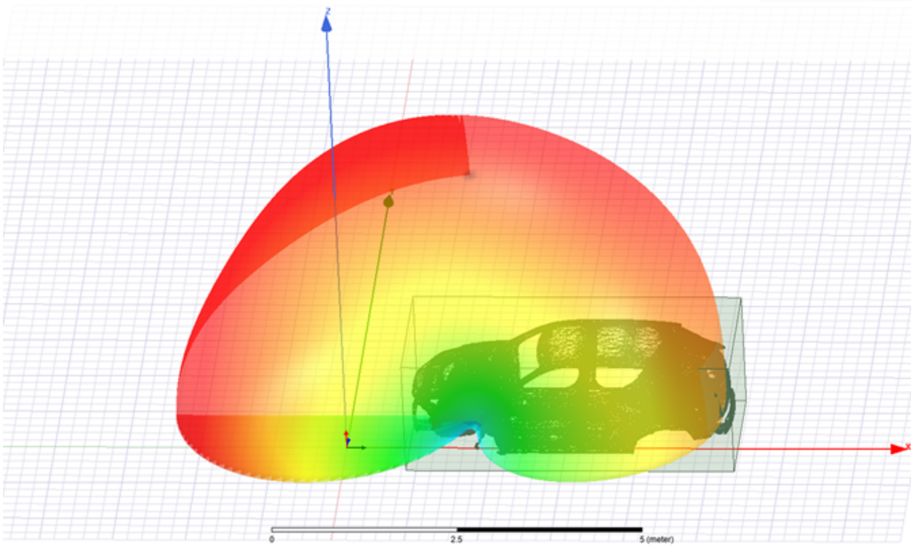

Figure 5.11: Radiated Pattern with Antenna along z-axis

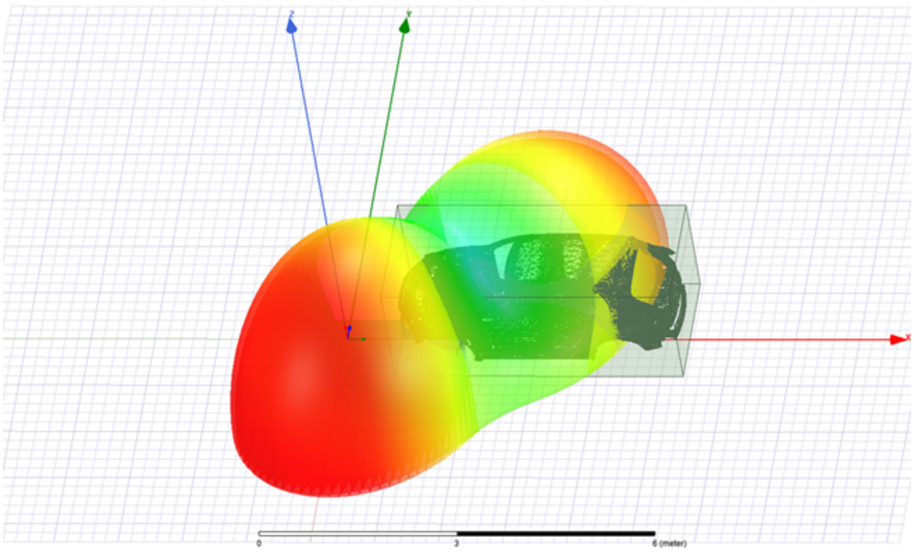

Figure 5.12: Radiated Pattern with Antenna along y-axis

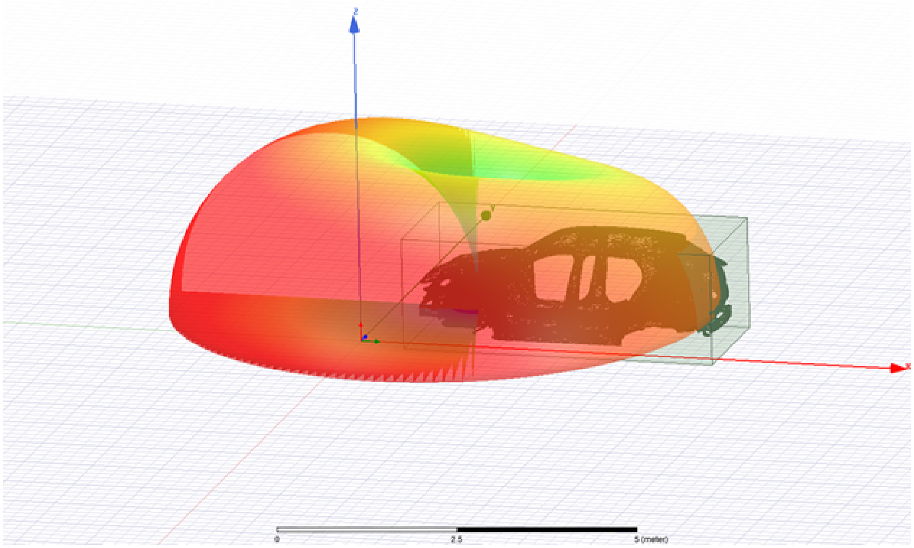

Figure 5.13: Radiated Pattern with Antenna along x-axis

5.2 Conclusion

Based on the comparison of the results with different orientations of dipole antenna, the polarization mode of the radiation source seems to have influence on E-field. But since the geometry is highly simplified and the AM antenna is not modeled, this investigation is not sufficient to be used as a proof to figure out the worst case.

In order to better understand the cost of running these different models, a simple comparison of time and memory is made as shown in Table 5.1. The data are from the models all using z-axis aligned antenna as an example. According to the comparison, the cost of simulation on vehicle increases rapidly with add-in components.

Table 5.1: Comparison of Simulation Cost

Model	Mesh Time	Real Solve Time	CPU Solve Time	Element Amount
Case 1	00:03:22	04:01:50	42:13:03	911,400
Case 2	01:21:24	12:49:24	59:21:13	1,620,552
Case 3	07:04:35	58:57:22	136:35:11	2,674,312

Therefore, all these models are successfully applied in the EM simulation. Based on this fact, the corresponding pre-process method is feasible.

6
Conclusion

6.1 Overall Conclusion

Several methods for utilizing geometry description from mechanical simulations as starting point for EM simulation mesh have been investigated. Special care has been taken to establish proper electrical connection in the simulation model. Two resulting feasible methods has been presented, of which one was used for performing proof of principle simulations.

6.2 Future Work

There are a lot of aspects could be improved based on the simulation method proposed in this report. This is only a qualitative work, and there is a possibility to make some quantitative simulations in the future if given more information of the components. For example, the robust radiated emission simulation model can be modified for further investigation such as the polarization influence both of the source and receiver.

Apart form the wrapping method applied in this report, another model with partial connection as shown in Figure 6.1 has not finished the simulation in this project. This model has an advantage as it can also simulate the magnetic field (H-field) distribution inside vehicle. The wrapped model cannot be used to investigate the H-field since there is no mesh operation applied to the inner volume of the closed wrapped surface. Therefore, if the acceptable computational complexity could be higher, the model with welding spots should be able to provide a more accurate result.

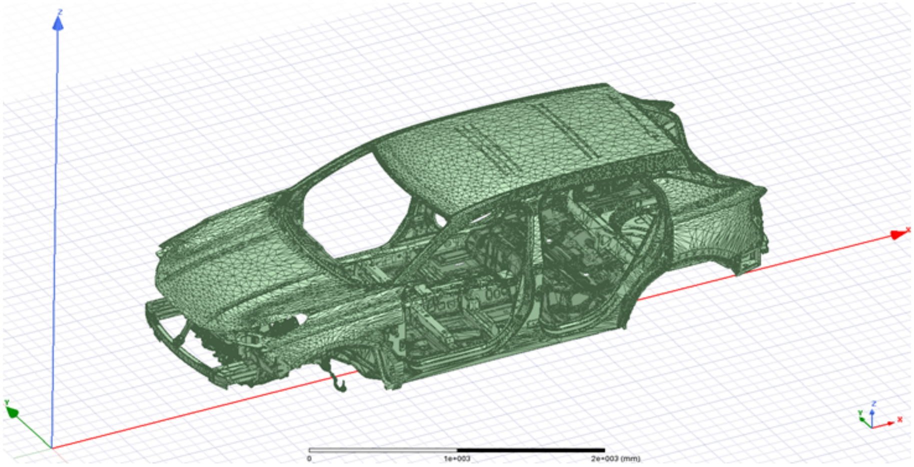

Figure 6.1: Complete Model with Welding Spots

Since the cable harness system is a very important part in the vehicle, and the rotation of cable harness has a strong influence on the common mode current [21] [22], it is also interesting to investigate the EMC performance of vehicle model with cable harness as shown in Figure 6.2.

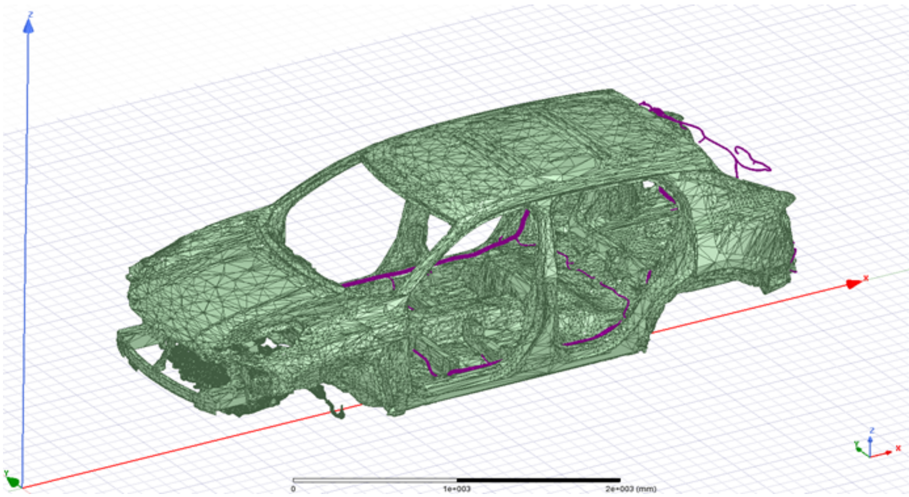

Figure 6.2: Vehicle Model with Cable inside

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