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Improvement of the Triggering Antenna in the Tyre Safety Systems

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Abstract – This paper presents the influence of the magnetic field of a triggering antenna in a Tire Pressure Monitoring System (TPMS) over the proper behaviour of the system. From the very beginning, the reader of this paper should know that this is not a matter of quantity, but a matter of quality, therefore the purpose of the simulations are to make a good representation of the magnetic field on the surrounding components in the car. The software used for simulating is ANSYS v11 – Academic Teaching Advanced, student version.

1

Introduction

- 1.1. Indirect TPMS**
- 1.2. Direct TPMS**
- 1.3. Components of the TPMS**
- 1.4. Current System Concepts**



Chapter I

Introduction

In any civilised nation today, public safety is the highest profile activity on virtually every government's agenda. But away from the surveillance satellites, bugged phone lines, and intercepted e-mails, less shadowy government agencies continue to strive to save us from the wider threats that compromise everyday life. High on the list of such dangers that we all take for granted — and also most often ignore — comes road safety, which can cost as many as 40,000 lives every year across Europe.

Car makers have in recent years made huge improvements to vehicle safety, many of which rely heavily on electronics content. Familiar examples include the ABS (antilock-braking systems) and ESP (electronic-stability programmes) that appear in so many of today's production vehicles.

But several, arguably more fundamental, steps can contribute to highway-accident reduction, such as ensuring that the vehicle is in fit condition for use. Within this context, tyre health is one of the greatest contributors to safety.

Studies in the United States — currently the world leader in legislating for tyre-safety issues — reveal that although some 85% of the population recognises the importance of maintaining properly inflated tyres, most drivers wait until the vehicle's service interval to have a garage technician check the tyres. A February 2001 study from the country's DOT (Department of Transportation) that surveyed 11,530 vehicles nationwide shows that 27% of passenger cars and 33% of light trucks operate with one or more substantially underinflated tyres. The result is that, in the United States alone, an estimated total of 23,000 crashes and 535 fatalities every year involve flat tyres or blowouts. Underinflated tyres are not necessarily obvious, because the circumference changes relatively little from 1 to 3 bar of internal pressure, and 30% underinflation is next-to-undetectable to a casual observer (**Figure 1.1**).



Figure 1.1 – The difference between a correctly inflated tire (LEFT) and one with only 70% pressure (RIGHT) is difficult for a typical driver to see.

Under inflated tyres also consume excess energy, with fuel consumption increasing by approximately 1% for every 0.2 bar of underinflation. Unsurprisingly then, vehicle manufacturers and regulatory authorities are keenly interested in techniques for TPMS (tyre-pressure-monitoring systems).

These groups recognised this requirement as long ago as 1970, but a cost-effective enabling technology simply wasn't available at that time. But today's technologies allow the US DOT to mandate that most vehicles built from now on will carry a TPMS.

Pioneers with systems in mass production include the United Kingdom's Schrader Electronics, which developed the systems that appear in, for example, many contemporary Frenchmanufactured cars. In Germany, a consortium of the country's leading motor manufacturers tasked Alligator Ventilfabrik and BERU with designing a cost-effective TPMS for mass production, with Alligator responsible for the valve assembly and BERU tackling the electronics content. Given the political impetus within the EU for traffic-accident reduction, it's reasonable to expect TPMS to become mandatory within the foreseeable future.

Direct vs. Indirect TPMS

During the phase-in period, NHTSA is allowing two compliance options: direct and indirect TPMS. A **direct TPMS** uses a pressure sensor inside each tire and a wireless transmitter to communicate the pressure from inside the tire to a central receiver module. An **indirect TPMS** uses a vehicle's antilock braking system (ABS) to determine changes in tire pressure.



1.1. Indirect TPMS

The ABS requires a sensor on each hub to monitor the rotational speed of each road wheel. The so-called indirect-TPMS method minimises implementation cost by taking advantage of the fact that ABS appears in virtually every production vehicle. The technique works by comparing the rotational speed of each wheel in normal driving mode and relies on a tyre that's substantially underinflated having a rolling diameter that's smaller than its counterparts. As a result, the errant tyre rotates faster than correctly inflated members of its group (typically, the partner wheel on the same axle). But some problems exist, such as the system's inability to detect tyre deflation of typically less than 30%. Also, tyre changes require resetting the system to relearn the dynamic relationship between each wheel, creating lifetime maintenance and calibration issues. And, because the system makes differential measurements, it can't independently treat each wheel. For example, no way exists to detect a case in which all four tyres are underinflated to a similar degree, which can easily occur with similar tyres over an extended period of neglect. Potential system improvements include analysing the resonant frequency of each wheel, but this approach isn't cost-effective, because it requires significant computational capacity.

1.2. Direct TPMS

The typical direct TPMS for vehicles includes 4 or 5 tire modules (depending on whether the spare has a sensor) and one central receiver module. A bare-bones tire module consists of a pressure sensor, temperature sensor, control module (such as an ASIC or an MCU), transmitter and antenna, and battery.

Direct measurement systems determine the actual individual wheel values for pressure and temperature. The measured values are sent by remote transmission together with an identification code to a control unit fitted in the vehicle. The pressure sensor elements generally operate on a micro-mechanical basis as part of an integrated circuit. The temperature is measured on the chip using a bandgap reference. Depending on the remote transmission conditions in the country of use, the data transmission takes place via frequency shift keying modulation (FSK) as a burst with 19kbit/s in each case in the 433MHz or 315MHz band. The telegram length is 96bits. Error protection is provided by the cyclic redundancy check algorithm (CRC). Special lithium batteries are used to power the tire electronics. Combined with the energy-optimised sensor electronics, they allow a service life of up to 10 years. The required service life of the batteries can be achieved by careful circuit design and a needs-based control of the measurement cycles and transmitter activity.

Within this context, the measurement cycles are defined depending on of the vehicle movement. Longer measurement cycles are possible if the vehicle is stationary;



the cycles are then cut appropriately if the vehicle is in motion and may even be measured in seconds if significant changes in the pressure are identified over time – i.e. if there is a tire defect or the tire is being inflated. The tire electronics autonomously recognizes vehicle movement using a roll switch.

An alternative is a needs-based triggering of the measurement via the reverse channel to the wheel electronics. The trigger transmitters required for this are installed in the wheel arches.

In addition to the clocking of measurement procedures, the trigger transmitters enable the wheel positions to be learned in a simple manner. The frequency band of around 125 kHz used for the trigger channel ensures that the range of the transmitted trigger signal remains low due to the small antenna structure in a ratio to the wavelength, which permits reliable control of the individual wheel electronics. Neighbouring wheels remain unaffected, thus enabling clear identification. Therefore, in a comparison of the direct and indirect measurement systems, BERU recognizes the clear advantages of the direct measurement system. This was also the basis for the decision in 1995 to develop a TPMS on this technological basis.

US Court of Appeals decision of Aug 6, 2003, effectively mandates that all TPMS for North American use shall employ a direct-pressure-measurement technique.

The fundamental requirement demands that the system generates a driver warning when the pressure in any one tyre, or in any combination of as many as four tyres, falls to 20% or more below the manufacturer's recommended cold-inflation pressure. Temperature measurement is also essential to ensure the long-term accuracy and reliability of a TPMS. All TPMS aim to withstand the -40 to +125°C automotive range. Popular wireless-mounting systems have a small sensor module that fits inside the tyre and carries the valve stem, with the valve-stem nut securing the assembly (**Figure 1.2**).



Figure 1.2 – BERU's sensor module mounts inside the tire on the valve stem



This module typically weighs 28 to 35g and requires a small balance correction elsewhere on the wheel assembly. The application has to withstand not only automotive-temperature extremes, but also extreme levels of acceleration and vibration. For example, at a vehicle speed of 250 km/hour, the module in a system such as Pi Research's TPMS for Formula One motor sport is exposed to as much as 2000g, as well as the constant vibration that road-surface irregularities cause. Also, the module must resist compounds that commonly appear in the application, which range from petrochemical ingress to the lubricants that ease tyre fitment. Conventional methods of preserving electronics within harsh automotive environments include conformal coatings and encapsulation within some type of epoxy - or polyurethane-based potting compound. The TPMS application complicates matters by needing an open port to measure pressure, which has led to some design approaches.

1.3. Components of the TPMS

A representative system consists of four functional blocks:

- the wheel electronics
- the digital antenna
- the trigger transmitter
- and a control unit

User interfaces and displays are also necessary for the driver.

1.3.1. *The wheel electronics*

The wheel electronics unit is the main component in the system. It is fitted in the tyre on the valve (**Figure 1.3**) so it must be able to deal with extreme conditions. It must withstand temperatures of between -40°C and $+120^{\circ}\text{C}$ in bursts up to $+150^{\circ}\text{C}$ – with acceleration values up to 2000g.

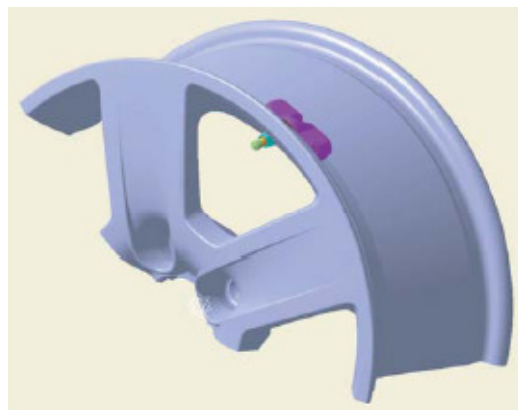


Figure 1.3 – The wheel electronic system is combined with the tyre valve and mounted on the rim



The housing has a spherical surface so it can be fitted to nearly all known rim types with only one design (**Figure 1.4**)

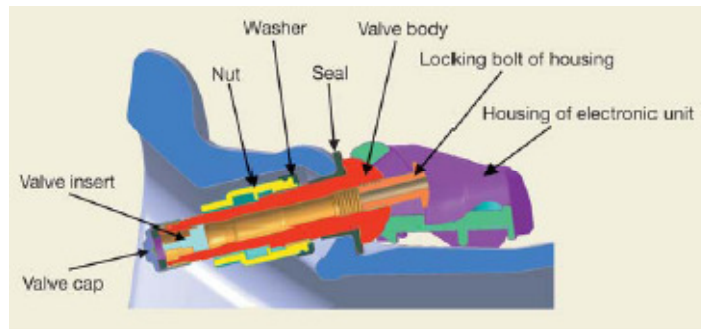


Figure 1.4 – The cross section of the wheel electronics shows how the system can be adapted to suit various rims

The unit is encapsulated to be protected from water, oil, dust or chemical residues and a Teflon filter maintains the required humidity inside the pressure sensor.

The wheel electronics contains three integrated circuits. The first circuit has a micro-mechanical structure for measuring and digitizing the values for pressure, temperature and acceleration. The value of acceleration is used as an auxiliary factor, so that it determines whether the wheel is moving or not and the system can respond by switching to another transmission mode. The second circuit contains a 433 MHz (or 315MHz) transmission channel to send back to the Control Unit information about the pressure and the temperature in the wheel. Basic systems employ transmit-only channels that take advantage of the unlicensed ISM (industrial, scientific and medical) bands. In this case, wheel sensor activities are autonomous of any central intelligence and require the accelerometer to control, through the third module, wake-up and sleep mode switching to conserve battery life. This module wakes up the system by receiving a trigger signal of 125KHz and setting it to an active mode.

1.3.2. The Digital Antenna

The digital antenna contains a 433 MHz (or 315 MHz) RF receiver with a demodulator and a data decoder. The received measurement values are transmitted to the control unit via a LIN bus interface. The main advantage of this concept comparing to previous systems is that no RF wiring is required in the vehicle to control the tyre pressure. First, the receiver transforms the 433 MHz (or 315MHz) signal to an intermediate frequency of 10.7 MHz, after preliminary filtering and second there is a demodulation, decoding and reformatting for the LIN protocol.

1.3.3. The Trigger Transmitter

The trigger transmitter contains the evaluation of the LIN telegram, in order to control and generate the trigger data, and the 125 kHz generator with a ferrite antenna as



a transmission element. Both the digital antenna and the trigger transmitter are waterproof and impact - protected in a robust housing and can therefore be fitted to the outside of the vehicle without difficulty.

1.3.4. The Control Unit

The control unit processes the information received from the digital antenna sends it via CAN bus to the car system and displays it on the monitor. Alarm algorithms and display strategies are implemented as a customer specific element of the overall system.

1.3.5. The Operating and Display Unit

The operating and display unit are coordinated to the vehicle's manufacturers and it has to suit the interior design of the car. It should be also taken into consideration the cost of the display unit. Therefore various versions are available, from a simple light control alarm, indicating just a low pressure in one of the tyres, to an alphanumerical display of both pressure and temperature values with color-coded status of the individual wheels.

1.4. Current Systems Concepts

Due to installation and costs it is more practical to fit TPMS with a central receiver unit, at least in the countries where radio regulation allow this. BERU developed three versions available on market.

1.4.1. Basic System

The basic system does not identify wheel's position so that it can be implemented at low cost and yet it can offer immediate pressure information. An alarm is released as soon as low pressure is identified, but not offering information about which wheel started the alarm. Individual wheel position pressure display is not possible either. Individual wheel detection takes place exclusively via the identification code of the wheel electronics. However, the system alarm thresholds must either be uniform for all wheels or must on one occasion be derived from the measured pressure values in the wheel electronics using a calibration switch and then allocated to the matching identification codes of the wheel electronics. The alarm display takes place using the driver information system without positional allocation.

1.4.2. Trigger System

If positional allocation is required in addition to the wheel electronics, the trigger system is the best technical solution compared to the other systems currently on offer.

The added number of components provides fast and reliable detection of the wheel positions. The transmitter is controlled by the central control unit. A trigger signal causes the allocated wheel electronics to record a new pressure and temperature measurement value and to transmit it as a radio telegram encoded as requested information.



Allocation to the wheel position is possible very quickly due to the correlation between a radio data set registered (marked) in the central receiver and the trigger request.

The trigger-controlled system provides the pressure information even before the driver sets off.

In this system, the target values for the tire pressures can be specified for each axle by control unit programming and can also be derived directly from the set pressures using a calibration modulator.

Figure 1.5 shows the components of the actual TSS.

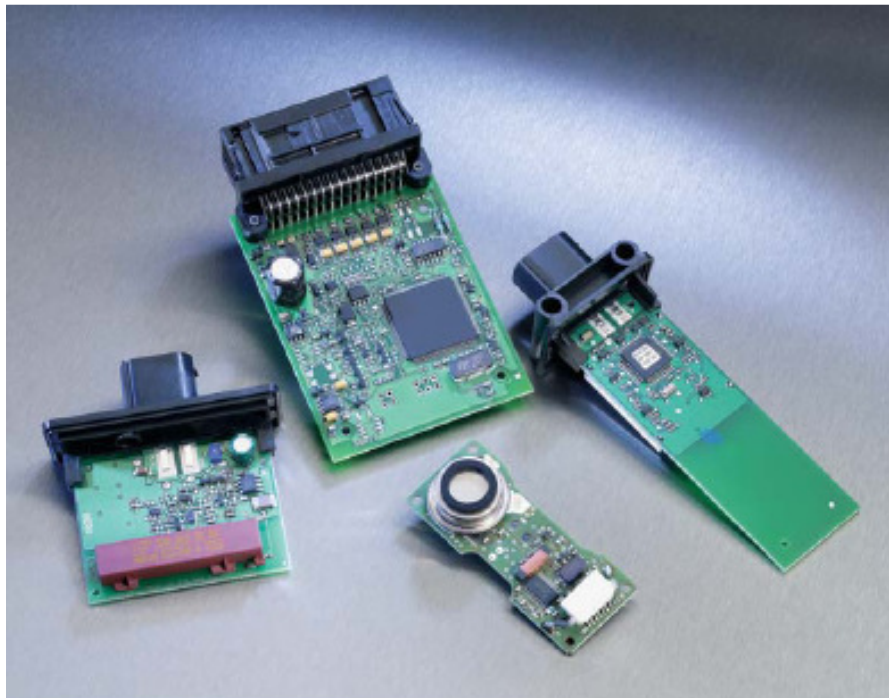


Figure 1.5: Components of the BERU-TSS generation 2 without housing, with visible construction - from the left: trigger transmitter, control unit, wheel electronics, digital antenna

1.4.3. Compact System

The latest development continues to reduce the number of system components. The BERU compact system (TSS 3rd generation) will consist only of a central receiver unit with an integrated control unit function and four wheel electronic systems.

Positional allocation takes place on the basis of the rotary direction signal, which the wheel electronic systems provide in the radio data, relating the information on the direction in which the vehicle is moving, in combination with the axle-specific separation from the fitted wheel electronic systems to a comparison of the various RF reception levels. This is achieved by the installation of the central receiver unit at the front or rear



of the vehicle in order to provoke these differences in the RF level. Definition of the target value for tire pressure takes place as described above. A monitor displays the warning and the positional information.

2

Objective



Chapter II

Objective

ANSYS designs, develops, markets and globally supports engineering simulation solutions used to predict how product designs will behave in manufacturing and real-world environments. ANSYS helps organizations achieve:

- Innovative and high-quality products and processes
- Fewer physical prototypes and test setups
- Faster return on investment due to reduced development time
- A more flexible and responsive information-based development process, enabling the modification of designs at later stages of development
- A front-end simulation strategy that offers a superior method for bringing products to market in less time and with fewer costs

ANSYS capabilities of simulation include:

[Electromagnetics](#)

Electromagnetic simulations are critical to electrical and electronic product designs across many industries. The ANSYS Electromagnetics solution addresses the analysis needs of two broad, but distinct electromagnetic market segments, high and low frequencies. This engineering software is a virtual prototyping tool that can replace many aspects of electromagnetics physical testing. This reduces product time to market, reduces development costs and allows the user to enhance and optimize the performance of products with minimal physical prototype costs.

[Explicit Dynamics](#)

Explicit dynamics analyses often deal with extremely short time durations, typically less than a second in the total transient, as well as high deformations, large strains, fracture, or complete material failure. Two products in the ANSYS suite address these dynamics simulations, and the right tool for the job depends highly on the application. ANSYS AUTODYN often is used in defense, homeland security and space industries, whereas ANSYS LS-DYNA has many applications in the metal forming and consumer product industries.



Fluid Dynamics

Understanding the motion of liquids and gases is crucial in many branches of engineering. Computational fluid dynamics (CFD) has become an integral part of the engineering design and analysis environment at many companies that need to predict the performance of new designs or processes before they are manufactured or implemented. CFD solutions from ANSYS, Inc. include ANSYS CFX and FLUENT software. Specialized models for combustion, reacting flows and radiation, rotating machinery, electronics cooling and many other applications, help provide the insight into equipment and processes required to increase production, improve longevity and decrease waste.

Fluid Structure Interaction

Fluid structure interaction (FSI) occurs when a fluid interacts with a solid structure, exerting pressure that may cause deformation in the structure and, thus, alter the flow of the fluid itself. FSI analysis is required for many industry applications, such as biomedical (elastic artery modeling for stent design), aerospace (foil flutter) and civil engineering (wind loading of structures). The ANSYS FSI solution provides designers and analysts with the most flexible and advanced coupled structural-fluid physics analysis tool available.

Mechanical

The ANSYS Mechanical family of products offers a full depth of analysis from concept simulation to advanced analysis; its breadth of simulation capabilities ranges from linear to nonlinear coupled physics analysis. The software provides simulation tools used widely across industry by designers to advanced analysts, providing a full complement of nonlinear and linear elements, material laws ranging from metal to rubber, and the most comprehensive set of solvers available. These tools tackle real-world analysis problems, making product development less costly and more reliable.

Meshing (Processes)

Meshing is an integral part of the CAE analysis process. The mesh influences the accuracy, convergence and speed of the solution. More importantly, the time it takes to create a mesh model is often a significant portion of the time it takes to get results from a CAE solution. From automatic meshing to highly crafted mesh, ANSYS provides the ultimate meshing solution.

Multiphysics

The ANSYS Multiphysics solution provides a comprehensive coupled physics tool combining structural, thermal, CFD, acoustic and electromagnetic simulation capabilities in a single software product. With the ANSYS Multiphysics solution, users can realize the benefits of the core physics of the entire ANSYS simulation suite in one convenient package. Applications include rotating machines (motors and alternators), sensors and actuators, power generators and transformer systems, and micro-electro mechanical systems (MEMS).

ANSYS 11.0 is a product of ANSYS, Inc. and it's a general-purpose finite element analysis (FEA) software package which provides a cost-effective way to explore the



performance of products or processes in a virtual environment. This type of product development is termed virtual prototyping.

With virtual prototyping techniques, users can iterate various scenarios to optimise the product long before the manufacturing is started. In this paper, ANSYS Electromagnetics is being used to simulate the magnetic field created by the triggering antenna of the TPMS. This magnetic field can create secondary magnetic fields through the metallic parts of the car which are not properly isolated and it can trigger the electronic part of the opposite wheel. On each engine ignition, the Tyre Safety System goes through a learning stage, comparing the new positions of the wheel with the old positions had in the history. If 2 electronic wheels respond to the same signal, then the Control Unit is not able to locate the position of the wheel. By proving to the customers which is the best approach for building their suspension parts of the vehicle, malfunctions like this can be avoided. This enables a reduction in the level of risk, and in the cost of ineffective designs.

3

Procedure

- 3.1. Theoretical Considerations**
- 3.2. Simulation Work**
- 3.3. Experimental Work**



Chapter III

Procedure

Everything is created step-by-step, starting with a two-dimensional modelling of a basic model – the triggering antenna and adding other parts to the simulation, ending up with a tri-dimensional simulation.

3.1. Theoretical Considerations

ANSYS is general-purpose finite element analysis (FEA) software package. Finite Element Analysis is a numerical method of deconstructing a complex system into very small pieces (of user-designated size) called elements. The software implements equations that govern the behaviour of these elements and solves them all, creating a comprehensive explanation of how the system acts as a whole. These results then can be presented in tabulated, or graphical forms.

3.1.1. Electromagnetic Field Fundamentals

Electromagnetic fields are governed by the following Maxwell's equations:

$$\nabla \times \{H\} = \{J\} + \left\{ \frac{\partial D}{\partial t} \right\} = \{J_s\} + \{J_e\} + \{J_v\} + \left\{ \frac{\partial D}{\partial t} \right\} \quad (3 - 1)$$

$$\nabla \times \{E\} = - \left\{ \frac{\partial B}{\partial t} \right\} \quad (3 - 2)$$

$$\nabla \cdot \{B\} = 0 \quad (3 - 3)$$

$$\nabla \cdot \{D\} = \rho \quad (3 - 4)$$

where:

$\nabla \times$ = curl operator

$\nabla \cdot$ = divergence operator

$\{H\}$ = magnetic field intensity vector

$\{J\}$ = total current density vector

$\{J_s\}$ = applied source current density vector

$\{J_e\}$ = induced eddy current density vector

$\{J_v\}$ = velocity current density vector



- $\{D\}$ = electric flux density vector
 t = time
 $\{E\}$ = electric field intensity vector
 $\{B\}$ = magnetic flux density vector
 ρ = electric charge density

The above field equations are supplemented by the constitutive relation that describes the behavior of electromagnetic materials. For problems considering saturable material without permanent magnets, the constitutive relation for the magnetic fields is:

$$\{B\} = [\mu]\{H\} \quad (3 - 5)$$

where:

μ = magnetic permeability matrix, in general a function of $\{H\}$

The magnetic permeability matrix $[\mu]$ may be input either as a function of temperature or field. Specifically, if $[\mu]$ is only a function of temperature,

$$[\mu] = \mu_0 \begin{bmatrix} \mu_{rx} & 0 & 0 \\ 0 & \mu_{ry} & 0 \\ 0 & 0 & \mu_{rz} \end{bmatrix}$$

where:

μ_0 = permeability of free space

μ_{rx} = relative permeability in the x-direction (input as MURX on **MP** command)

If $[\mu]$ is only a function of field,

$$[\mu] = \mu_\eta \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

where:

μ_η = permeability derived from the input B versus H curve (input with **TB**,BH)

The constitutive relations for the related electric fields are:

$$\{J\} = [\sigma][\{E\} + \{v\} \times \{B\}] \quad (3 - 6)$$

$$\{D\} = [\varepsilon]\{E\} \quad (3 - 7)$$

where:

$$[\sigma] = \begin{bmatrix} \sigma_{xx} & 0 & 0 \\ 0 & \sigma_{yy} & 0 \\ 0 & 0 & \sigma_{zz} \end{bmatrix} = \text{electrical conductivity matrix}$$

$$[\varepsilon] = \begin{bmatrix} \varepsilon_{xx} & 0 & 0 \\ 0 & \varepsilon_{yy} & 0 \\ 0 & 0 & \varepsilon_{zz} \end{bmatrix} = \text{permittivity matrix}$$



$$\{v\} = \begin{Bmatrix} v_x \\ v_y \\ v_z \end{Bmatrix} = \text{velocity vector}$$

σ_{xx} = conductivity in the x-direction (input as inverse of RSVX on **MP** command)

ϵ_{xx} = permittivity in the x-direction (input as PERX on **MP** command)

The solution of magnetic field problems is commonly obtained using potential functions. Two kinds of potential functions, the magnetic vector potential and the magnetic scalar potential are used depending on the problem to be solved. Factors affecting the choice of potential include: field dynamics, field dimensionality, source current configuration, domain size and discretization.

The applicable regions are shown below, in **Figure 3.1**:

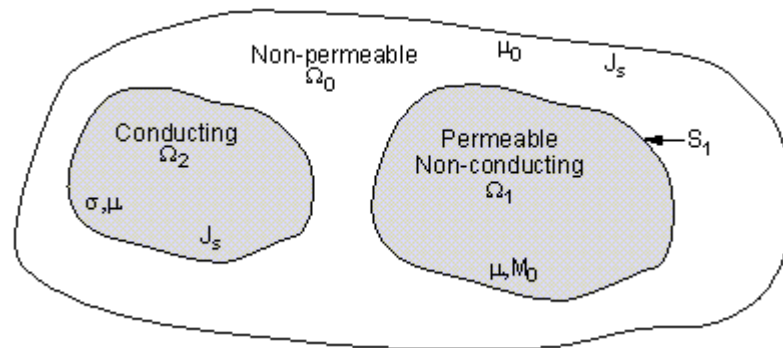


Figure 3.1 – Electromagnetic Field Regions

where:

- Ω_0 = free space region
- Ω_1 = nonconducting permeable region
- Ω_2 = conducting region
- μ = permeability of iron
- μ_0 = permeability of air
- M_0 = permanent magnets
- S_1 = boundary of W1
- σ = conductivity
- $\Omega = \Omega_1 + \Omega_2 + \Omega_0$

3.1.1.1. *Magnetic Scalar Potential*

The magnetic scalar potential method won't be discussed in this chapter, as it was not used for the simulations.



3.1.1.2. Magnetic Vector Potential

The vector potential method as implemented in [PLANE53](#), and [SOLID97](#) for both 2-D and 3-D electromagnetic fields is discussed in this section. Considering static and dynamic fields and neglecting displacement currents (quasi-stationary limit), the following subset of Maxwell's equations apply:

$$\nabla \times \{H\} = \{J\} \quad (3 - 8)$$

$$\nabla \times \{E\} = -\frac{\partial B}{\partial t} \quad (3 - 9)$$

$$\nabla \cdot \{B\} = 0 \quad (3 - 10)$$

In the entire domain, Ω , of an electromagnetic field problem a solution is sought which satisfies the relevant Maxwell's ([Equation 3–8](#)) thru ([Equation 3–9](#)). See [Figure 3.1: "Electromagnetic Field Regions"](#) for a representation of the problem domain Ω .

A solution can be obtained by introducing potentials which allow the magnetic field $\{B\}$ and the electric field $\{E\}$ to be expressed as

$$\{B\} = \nabla \times \{A\} \quad (3 - 11)$$

$$\{E\} = -\left\{\frac{\partial A}{\partial t}\right\} - \nabla V \quad (3 - 12)$$

where:

$\{A\}$ = magnetic vector potential

V = electric scalar potential

These specifications ensure the satisfaction of two of Maxwell's equations, ([Equation 3–9](#)) and ([Equation 3–10](#)). What remains to be solved is Ampere's law, ([Equation 3–8](#)) and the divergence free property of current density. Additionally, to ensure uniqueness of the vector potential, the Coulomb gauge condition is employed. The resulting differential equations are:

$$\nabla \times [v] \nabla \times \{A\} - \nabla v_e \nabla \cdot \{A\} + [\sigma] \left\{\frac{\partial A}{\partial t}\right\} + [\sigma] \nabla V - \{V\} \times [\sigma] \nabla \times \{A\} = \{0\} \text{ in } \Omega_2 \quad (3 - 13)$$

$$\nabla \cdot \left([\sigma] \left\{\frac{\partial A}{\partial t}\right\} - [\sigma] \nabla V + \{V\} \times [\sigma] \nabla \times \{A\} \right) = \{0\} \text{ in } \Omega_2 \quad (3 - 14)$$

$$\nabla \times [v] \nabla \times \{A\} - \nabla v_e \nabla \cdot \{A\} = \{J_s\} + \nabla \times \frac{1}{v_0} [v] \{M_0\} \text{ in } \Omega_0 + \Omega_1 \quad (3 - 15)$$

where:

$$v_e = \frac{1}{3} \text{tr}[v] = \frac{1}{3}(v(1,1) + v(2,2) + v(3,3))$$

$\{M_0\}$ = remanent intrinsic magnetization vector

$[v]$ = reluctivity matrix = $[\mu] - 1$

v_0 = reluctivity of free space = $\frac{1}{\mu_0}$



Of course these equations are subject to the appropriate boundary conditions. This system of simplified Maxwell's equations with the introduction of potential functions has been used for the solutions of 2-D and 3-D, static and dynamic fields.

3.1.2. Derivation of Electromagnetic Matrices

The finite element matrix equations can be derived by variational principles. These equations exist for linear and nonlinear material behavior as well as static and transient response. Based on the presence of linear or nonlinear materials (as well as other factors), the program chooses the appropriate Newton-Raphson method. The user may select another method.

3.1.2.1. Magnetic Scalar Potential

The scalar potential formulations are restricted to static field analysis with partial orthotropic nonlinear permeability.

3.1.2.2. Magnetic Vector Potential

The vector potential formulation is applicable to both static and dynamic fields with partial orthotropic nonlinear permeability. The basic equation to be solved is of the form:

$$[\bar{C}]\{\dot{u}\} + [\bar{K}]\{u\} = \{\bar{J}_i\} \quad (3 - 16)$$

The terms of this equation are defined below.

➤ Degrees of Freedom

$$\{\dot{u}\} = \begin{Bmatrix} \{A_e\} \\ \{v_e\} \end{Bmatrix} \quad (3 - 17)$$

where:

$\{A_e\}$ = magnetic vector potentials (input/output as AX,AY,AZ)

$\{v_e\}$ = time integrated electrical scalar potential ($v = \int V dt$) (input/output as VOLT)

The VOLT DOF is a time integrated electric potential to allow for symmetric matrices.

➤ Coefficient Matrices

$$[\bar{K}] = \begin{bmatrix} [K^{AA}] & [0] \\ [K^{VA}] & [0] \end{bmatrix} \quad (3 - 18)$$

$$[K^{AA}] = [K^L] + [K^N] + [K^G] \quad (3 - 19)$$

$$[K^L] = \int_{vol} (\nabla \times [N_A]^T)^T [v] (\nabla \times [N_A]^T - [N_A][\sigma] (\{V\} \times \nabla \times [N_A]^T)) d(vol) \quad (3 - 20)$$

$$[K^G] = \int_{vol} (\nabla \cdot [N_A]^T)^T [v] (\nabla \cdot [N_A]^T) d(vol) \quad (3 - 21)$$



$$[K^N] = 2 \int_{vol} \frac{dv_h}{d(|B|^2)} \left(\{B\}^T (\nabla \times [N_A]^T) \right)^T \left(\{B\}^T (\nabla \times [N_A]^T) \right) d(vol) \quad (3 - 22)$$

$$[K^{VA}] = - \int (\nabla [N]^T)^T [\sigma] \{V\} \times \nabla \times [N_A]^T d(vol) \quad (3 - 23)$$

$$[C] = \begin{bmatrix} [C^{AA}] & [C^{AV}] \\ [C^{AV}]^T & [C^{VV}] \end{bmatrix} \quad (3 - 24)$$

$$[C^{AA}] = \int_{vol} [N_A][\sigma][N_A]^T d(vol) \quad (3 - 25)$$

$$[C^{AV}] = \int_{vol} [N_A][\sigma]\{N\}^T d(vol) \quad (3 - 26)$$

$$[C^{VV}] = \int_{vol} (\nabla \{N\}^T)^T [\sigma] \nabla \{N\}^T d(vol) \quad (3 - 27)$$

➤ **Applied Loads**

$$\{J_t\} = \begin{Bmatrix} \{J^A\} \\ \{I^t\} \end{Bmatrix} \quad (3 - 28)$$

$$\{J^A\} = \{J^S\} + \{J^{pm}\} \quad (3 - 29)$$

$$\{J^S\} = \int_{vol} \{J_s\} [N_A]^T d(vol) \quad (3 - 30)$$

$$\{J^{pm}\} = \int_{vol} (\nabla \times [N_A]^T)^T \{H_c\} d(vol) \quad (3 - 31)$$

$$\{I^t\} = \int_{vol} \{J_t\} [N_A]^T d(vol) \quad (3 - 32)$$

where:

$[N_A]$ = matrix of element shape functions for $\{A\}$

$\{A\} = [N_A]^T \{A_e\}; \{A_e\}^T = \left[\{A_{xe}\}^T \{A_{ye}\}^T \{A_{ze}\}^T \right]$

$[N]$ = vector of element shape functions for $\{V\}$ ($V = \{N\}^T \{V_e\}$)

$\{J_s\}$ = source current density vector (input as JS on **BFE** command)

$\{J_t\}$ = total current density vector (input as JS on **BFE** command) (valid for 2-D analysis only)

vol = volume of the element

$\{H_c\}$ = coercive force vector (input as MGXX, MGYY, MGZZ on **MP** command)

v_o = reluctivity of free space (derived from value using MUZRO on **EMUNIT** command)

$[v]$ = partially orthotropic reluctivity matrix (inverse of $[\mu]$, derived from input material property curve B versus H (input using **TB**,BH command))



$$\frac{dv_h}{d(|B|^2)} = \text{derivate of reluctivity with respect to the magnitude of magnetic flux squared}$$

(derived from input material property curve B versus H(input using **TB**,BH) command)

$[\sigma]$ = orthotropic conductivity (input as RSVX, RSVY, RSVZ on **MP** command (inverse)) (see [\(Equation 3-6\)](#))

$\{V\}$ = velocity vector

The material property curve is input in the form of B values versus H values and is then converted to a spline fit curve of v versus $|B|^2$ from which the isotropic reluctivity terms v_h and $\frac{dv_h}{d(|B|^2)}$ are evaluated.

The above element matrices and load vectors are presented for the most general case of a vector potential analysis. Many simplifications can be made depending on the conditions of the specific problem. In 2-D there is only one component of the vector potential as opposed to three for 3-D problems (AX, AY, AZ).

For 2-D dynamic analyses a current density load of either source ($\{J_s\}$) or total $\{J_t\}$ current density is valid. In 3-D only source current density is allowed.

3.1.3. Electromagnetic Field Evaluations

The basic magnetic analysis results include magnetic field intensity, magnetic flux density, magnetic forces and current densities. These types of evaluations are somewhat different for magnetic scalar and vector formulations. The basic electric analysis results include electric field intensity, electric current densities, electric flux density, Joule heat and stored electric energy.

3.1.3.1. Magnetic Scalar Potential Results

It is not to be discussed in this paper.

3.1.3.2. Magnetic Vector Potential Results

The magnetic flux density is the first derived result. It is defined as the curl of the magnetic vector potential. This evaluation is performed at the integration points using the element shape functions:

$$\{B\} = \nabla \times [N_A]^T \{A_e\} \quad (3 - 33)$$

where:

$\{B\}$ = magnetic flux density (output as B)

$\nabla \times$ = curl operator

$[N_A]$ = shape functions

$\{A_e\}$ = nodal magnetic vector potential

Then the magnetic field intensity is computed from the flux density:

$$\{H\} = [v]\{B\} \quad (3 - 34)$$

where:



$\{H\}$ = magnetic field intensity (output as H)

$[v]$ = reluctivity matrix

Nodal values of field intensity and flux density are computed from the integration point value. Magnetic forces are also available and are discussed below.

For a vector potential transient analysis current densities are also calculated.

$$\{J_t\} = \{J_e\} + \{J_s\} + \{J_v\} \quad (3 - 35)$$

where:

$\{J_t\}$ = total current density

$$\{J_e\} = -[\sigma] \left\{ \frac{\partial A}{\partial t} \right\} = -[\sigma] \frac{1}{n} \sum_{i=1}^n [N_A]^T \{A_e\} \quad (3 - 36)$$

where:

$\{J_e\}$ = current density component due to $\{A\}$

$[\sigma]$ = conductivity matrix

n = number of integrating points

$[N_A]$ = element shape functions for $\{A\}$ evaluated at the integration points

$\{A_e\}$ = time derivative of magnetic vector potential

and

$$\{J_s\} = -[\sigma] \nabla V = [\sigma] \frac{1}{n} \sum_{i=1}^n \nabla \{N\}^T \{V_e\} \quad (3 - 37)$$

where:

$\{J_s\}$ = current density component due to V

∇ = divergence operator

$\{V_e\}$ = electric scalar potential

$\{N\}$ = element shape functions for V evaluated at the integration points

and

$$\{J_v\} = \{V\} \times \{B\} \quad (3 - 38)$$

where:

$\{J_v\}$ = velocity current density vector

$\{V\}$ = applied velocity vector

$\{B\}$ = magnetic flux density (see [Equation 3–33](#))



3.2. Simulation Work

The ANSYS program is organized into two basic levels:

- Begin level
- Processor (or Routine) level

The *Begin level* acts as a gateway into and out of the ANSYS program. It is also used for certain global program controls such as changing the jobname, clearing (zeroing out) the database, and copying binary files. When the program is entered the first, that is the Begin level.

At the *Processor level*, several processors are available. Each processor is a set of functions that perform a specific analysis task. For example, the general preprocessor (PREP7) is where the model is being built, the solution processor (SOLUTION) is used for applying loads and obtain the solution, and the general postprocessor (POST1) is used for evaluate the results of a solution.

Building a finite element model requires more time than any other part of the analysis. First, a jobname and analysis title are specified. Then, the PREP7 preprocessor is used to define the element types, element real constants, material properties, and the model geometry.

- **Defining Element Types:** An element type is identified by a name (8 characters maximum), such as [PLANE53](#), consisting of a group label (PLANE) and a unique, identifying number (53). The element is selected from the library for use in the analysis by inputting its name on the element type command [\[ET\]](#).
- **Defining Element Real Constants:** Usually comprising the element's geometric properties, such as thickness or cross-sectional area. Real constant set is not necessary for these simulations.
- **Defining Material Properties:** Various material properties are used for each element type. All material properties can be input as functions of temperature ([MPTEMP](#)). Some properties for non-thermal analyses are called *linear* properties because typical solutions with these properties require only a single iteration. Properties such as magnetic field data are called *nonlinear* because an analysis with these properties requires an iterative solution. Material properties are input with the [MP](#) family of commands while nonlinear properties are input with the [TB](#) family of commands.
- **Building the Geometry Model and Meshing:** There are two methods to create the finite element model: *solid modelling* and *direct generation*. With *solid modelling*, it is described the geometric shape of the model, then the ANSYS program is instructed to automatically *mesh* the geometry with nodes and elements. The size and shape in the elements that the program creates can be controlled by the user. With *direct generation*, it is "manually" defined the location of each node and the connectivity of each element. The purpose of using a solid model is to relieve the



user of the time-consuming task of building a complicated finite element model by direct generation. Some solid modeling and meshing operations can help to speed up the creation of the final analysis model. Therefore, this is the appropriate method used in this simulations.

After the model was built, a mesh is necessary. There are 2 possibilities to mesh the model: *free meshing* and *mapped meshing*. A *free* mesh has no restrictions in terms of element shapes, and has no specified pattern applied to it. A *mapped* mesh is restricted in terms of the element shape it contains and the pattern of the mesh. A mapped area mesh contains either only quadrilateral or only triangular elements, while a mapped volume mesh contains only hexahedron elements. In addition, a mapped mesh typically has a regular pattern, with obvious rows of elements. See **Figure 3.2** for understanding better free meshing and mapped meshing.

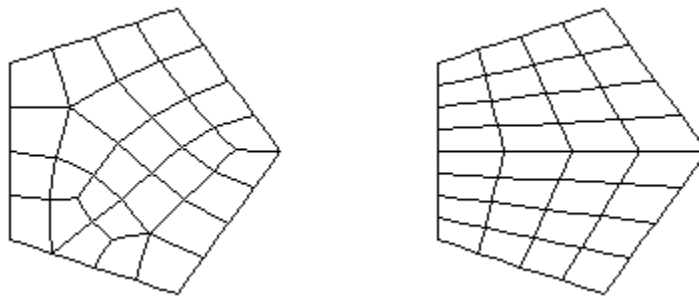


Figure 3.2 – Free and Mapped Meshes

Both types of meshing were used for modeling, [MSHKEY](#) command gives the option to choose between a free or a mapped mesh. One option key of this command allows the user to use mapped meshing if possible, otherwise use free meshing.

The process for generating a mesh of nodes and elements consists of three general steps:

1. Set the element attributes: Assigning the element attributes to the solid model entities allows to preassign attributes for each region of the model. By using this method, it can be avoided having to reset attributes in the middle of meshing operations. Attributes were assigned to areas using the [AATT](#) command.
2. Set mesh controls (optional): *Mesh controls* allow to establish such factors as the element shape, midside node placement, and element size to be used in meshing the solid model. This step is one of the most important of the entire analysis, for the decisions that are made at this stage in the model development will profoundly affect the accuracy and economy of the analysis.

Element shapes are specified using the [MSHAPE](#) command. Element size on lines is controlled by the [LESIZE](#) command.

Mesh density is extremely important. If the mesh is too coarse, the results can contain serious errors. If the mesh is too fine, it will waste computer resources,



experience excessively long run times, and the model may be too large to run on the computer system.

3. Meshing the model: Once it was built the solid model, established element attributes, and set meshing controls, everything is ready to generate the finite element mesh. **AMESH** command was used to generate area elements on areas and **VMESH** command was used to generate volume elements in volumes.

Next step is to use the SOLUTION processor for applying the loads. The word *loads* in ANSYS terminology includes boundary conditions *and* externally or internally applied forcing functions. Examples of loads in different disciplines are:

Structural: displacements, velocities, accelerations, forces, pressures, temperatures (for thermal strain), gravity

Thermal: temperatures, heat flow rates, convections, internal heat generation, infinite surface

Magnetic: magnetic potentials, magnetic flux, magnetic current segments, source current density, infinite surface

Electric: electric potentials (voltage), electric current, electric charges, charge densities, infinite surface

Fluid: velocities, pressures

Loads are divided into six categories: DOF constraints, forces (concentrated loads), surface loads, body loads, inertia loads, and coupled-field loads.

A *DOF constraint* fixes a degree of freedom (DOF) to a known value. Examples of constraints are specified displacements and symmetry boundary conditions in a structural analysis, prescribed temperatures in a thermal analysis, and flux-parallel boundary conditions.

In a structural analysis, a DOF constraint can be replaced by its differentiation form, which is a velocity constraint. In a structural transient analysis, an acceleration can also be applied, which is the second order differentiation form of the corresponding DOF constraint.

A *force* is a concentrated load applied at a node in the model. Examples are forces and moments in a structural analysis, heat flow rates in a thermal analysis, and current segments in a magnetic field analysis.

A *surface load* is a distributed load applied over a surface. Examples are pressures in a structural analysis and convections and heat fluxes in a thermal analysis.

A *body load* is a volumetric or field load. Examples are temperatures and fluences in a structural analysis, heat generation rates in a thermal analysis, and current densities in a magnetic field analysis.

Inertia loads are those attributable to the inertia (mass matrix) of a body, such as gravitational acceleration, angular velocity, and angular acceleration. You use them mainly in a structural analysis.

Coupled-field loads are simply a special case of one of the above loads, where results from one analysis are used as loads in another analysis. For example, you can apply magnetic forces calculated in a magnetic field analysis as force loads in a structural analysis.



Loads can be defined directly on the solid model at any time before actually initiating the solution. Thus, solid model loads may be defined before or after finite element meshing. Solid model loads will be transferred to the finite element model automatically at the begin of the solution calculations (when issuing a **SOLVE** command), or they can be transferred "manually".

In the solution phase of an analysis, the computer takes over and solves the simultaneous set of equations that the finite element method generates. The results of the solution are:

- Nodal degree of freedom values, which form the primary solution
- Derived values, which form the element solution.

The element solution is usually calculated at the elements' integration points. The ANSYS program writes the results to the database as well as to the results file.

Postprocessing (POST1) means reviewing the results of an analysis. It is probably the most important step in the analysis, because it is the way to try to understand how the applied loads affect the design, how good the finite element mesh is, and so on. POST1 allows to review the results over the entire model at specific load steps and substeps (or at specific time-points or frequencies).

The solution phase calculates two types of results data:

- *Primary data* consist of the degree-of-freedom solution calculated at each node: displacements in a structural analysis, temperatures in a thermal analysis, magnetic potentials in a magnetic analysis, and so on. These are also known as nodal solution data.
- *Derived data* are those results calculated from the primary data, such as stresses and strains in a structural analysis, thermal gradients and fluxes in a thermal analysis, magnetic fluxes in a magnetic analysis, etc. They are typically calculated for each element and may be reported at any of the following locations: at all nodes of each element, at all integration points of each element, or at the centroid of each element. Derived data are also known as element solution data, except when they are averaged at the nodes. In such cases, they become nodal solution data.

POST1, the general postprocessor, is used to review analysis results over the entire model, or selected portions of the model, for a specifically defined combination of loads at a single time (or frequency). POST1 has many capabilities, ranging from simple graphics displays and tabular listings to more complex data manipulations.

The first step in POST1 is to read data from the results file into the database. To do so, *model data* (nodes, elements, etc.) must exist in the database. The database should contain the *same* model for which the solution was calculated, including the element types, nodes, elements, element real constants, material properties, and nodal coordinate systems.

After model data are in the database, the results data from the results file are being load by issuing the following command: **SET**. The **SET** command reads results data over the entire model from the results file into the database for a particular loading condition, replacing any data previously stored in the database. The boundary condition information (constraints and force loads) is also read in, *but only if either element nodal loads or reaction loads are available*.



Once the desired results data are stored in the database, they can be reviewed through graphics displays and tabular listings. In addition, the results data can be mapped onto a path.

Graphics displays are perhaps the most effective way to review results. The following types of graphics can be displayed in POST1:

- Contour displays
- Deformed shape displays
- Vector displays
- Path plots
- Reaction force displays
- Particle flow traces.

Not all of these displays are used for the simulations.

The triggering antenna (**Figure 3.3**) is made out of a copper wire wound – about 180-190 turns – on a ferrite core of 40 mm length and 5.7 mm diameter. It is situated at about 10 to 80 cm from the electronic part in the wheel and about 15 to 40 cm from the suspensions part. It is triggered by a low frequency of 125kHz.

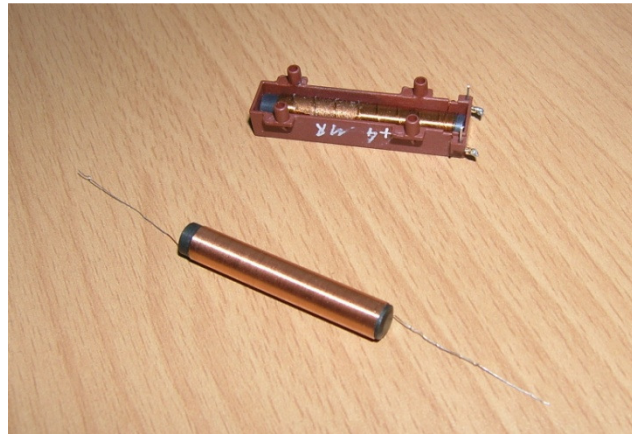


Figure 3.3 – Trigger antenna

3.2.1. 2-D Modeling

2-D SOLID analysis models are used for thin planar structures (plane stress), "infinitely long" structures having a constant cross section (plane strain), or axisymmetric solid structures.

The two-dimensional simulations begin with the easiest and the most convenient one: the triggering antenna which creates the main magnetic field. When creating a 2-D model it is better to use a simplified geometry of the analyzed part by specifying any kind of symmetry of the model and in this case, a quarter geometry of the antenna can be used, due to axial symmetry. By applying the right boundary conditions, this model can be viewed as a tri-dimensional one and the results are more accurate.

Each simulation starts by entering the begin level of the ANSYS software, where the name of the database to be created and of the project are specified. The title should



reflect the problem being analyzed and this helps to distinguish the analysis problem from others that may use similar model geometry or physics.

```
/FILNAME,antenna,0
/title,Trigger Antenna - Quarter Modeling, Axisymmetric
```

Next, the PREP7 preprocessor is used to create the geometry of the model and to mesh it. Parameters for building the geometry are defined, using the ***SET** command. These parameters can ease the work and later on they can be modified for a minor change of the geometry. Major changes of the geometry need, in most of the cases, changes in the whole program. Another choice that it is good to make in the beginning is to specify the system of units, using **EMUNIT** command. Using the MKS label the system of units was set to rationalized MKS system of units (meters, amperes, henries, webbers, etc.). Free-space permeability is set to $4\pi \times 10^{-7}$ henries/meter. Free-space permittivity is set to 8.85×10^{-12} F/m.

```
/PREP7
EMUNIT,MKS
*SET,l,40e-3
*SET,r,2.85e-3
*SET,n,190
*SET,d_wire,0.17e-3
*SET,l_wire,n*d_wire
*SET,r1,1.5
*SET,r2,1.55
*SET,copper,1.72e-8
*SET,ferrite,5
*SET,ip,0.42
```

l is the length of the ferrite core;

r is the radius of the ferrite core;

n is the number of windings on the core;

d_{wire} is the diameter of the copper wire;

l_{wire} is the total length of the wound copper wire on the ferrite core, therefore it was referred as the number of windings multiplied by the diameter of the wire;

r1 is the radius of the circle which is used to model the air surrounding the coil. We are interested on the magnetic field density at an approximate 1 meter distance away from the coil, this is the reason why it was defined such a big air area around the antenna;

r2 is the circle which together with *r1* help to define an open boundary of the field problem;

copper and *ferrite* are the variables used to define the resistivity of these materials;

ip is the current flowing through one winding of the coil.

The element types were next to be specified, using the **ET** command which defines a local element type from the element library. For this simulation, 2 element types were used: **PLANE53** with KEYOPT(3)=1 for axial symmetry, a second **PLANE53** element with the additional KEYOPT(1)=1 for AZ and VOLT degree of freedom (DOF) used to



mesh the copper coil, [INFIN110](#) with KEYOPT(2)=1 for matching the higher order element [PLANE53](#), and KEYOPT(3)=1 for axial symmetry.

```

ET,1,PLANE53
KEYOPT,1,1,0
KEYOPT,1,2,0
KEYOPT,1,3,1
KEYOPT,1,4,0
KEYOPT,1,5,0
KEYOPT,1,7,0
!*
ET,2,PLANE53
KEYOPT,2,1,1
KEYOPT,2,2,0
KEYOPT,2,3,1
KEYOPT,2,4,0
KEYOPT,2,5,0
KEYOPT,2,7,0
!*
ET,3,INFIN110
KEYOPT,3,1,0
KEYOPT,3,2,1
KEYOPT,3,3,1
KEYOPT,3,6,0

```

[PLANE53](#) models 2-D (planar and axisymmetric) magnetic fields. The element is defined by 8 nodes and has up to 4 degrees of freedom per node: z component of the magnetic vector potential (AZ), time-integrated electric scalar potential (VOLT), electric current (CURR), and electromotive force (EMF). [PLANE53](#) is based on the magnetic vector potential formulation and is applicable to the following low-frequency magnetic field analyses: magnetostatics, eddy currents (AC time harmonic and transient analyses), voltage forced magnetic fields (static, AC time harmonic and transient analyses), and electromagnetic-circuit coupled fields (static, AC time harmonic and transient analyses). The element has nonlinear magnetic capability for modeling B-H curves or permanent magnet demagnetization curves.

A single layer of [INFIN110](#) elements is used to represent an exterior sub-domain of semi-infinite extent. The layer models the effect of far-field decay in magnetic, electrostatic, thermal, or electric current conduction analyses.

Next step was to define materials properties:

- air was used as the first material, with a constant permeability of 1;
- the copper coil was modeled by the second material, using a constant permeability of 1 and a constant resistivity of $1.72e-8 \Omega m$
- the ferrite core was represented by the third material, with a non-linear characteristic and a constant resistivity of $5 \Omega m$



```
MPTEMP,,,,,,,,
MPTEMP,1,0
MPDATA,MURX,1,,1
!
MPTEMP,,,,,,,,
MPTEMP,1,0
MPDATA,MURX,2,,1
MPDATA,RSVX,2,,copper
!
MPTEMP,,,,,,,,
MPTEMP,1,0
MPDATA,RSVX,3,,ferrite
TB,BH,3,1,16,
TBTEMP,0
TBPT,,15,0.2
TBPT,,19,0.25
TBPT,,25,0.285
TBPT,,29,0.3
TBPT,,48,0.35
TBPT,,75,0.39
TBPT,,90,0.4
TBPT,,100,0.405
TBPT,,125,0.415
TBPT,,150,0.423
TBPT,,175,0.425
TBPT,,200,0.428
TBPT,,225,0.43
TBPT,,250,0.431
TBPT,,500,0.435
TBPT,,1000,0.44
TBPLOT,BH,3
```

The magnetization curve of this ferrite material used for the core can be seen in the **Figure 3.4**. It is interesting to see if the material works on its linear portion, which means it doesn't reach the saturation. The working point of the ferrite is for approximate $H=13A/m$ and $B=0.15T$, and by zooming in on the curve (**Figure3.5**) it can be noticed that this point is on the linear portion. Therefore, we can easily work with the prescribed current and the low frequency of 125KHz.

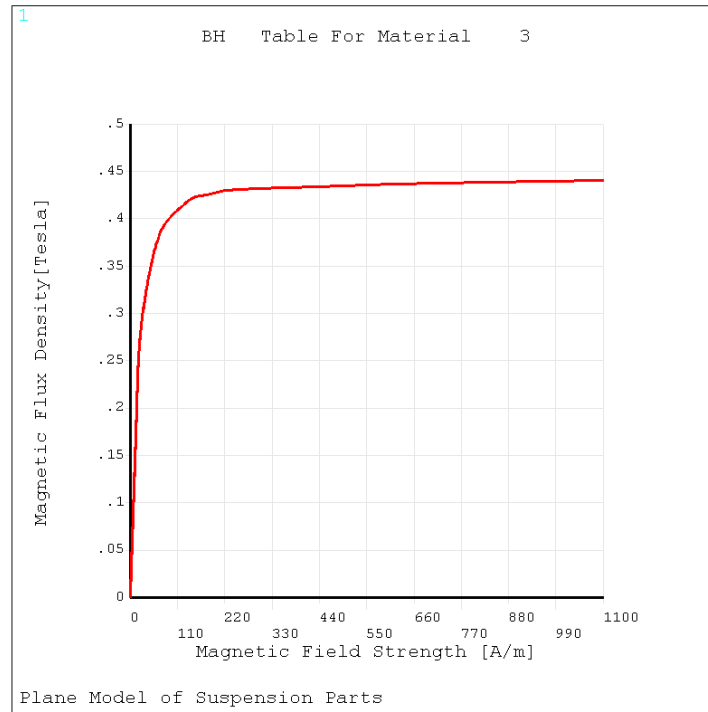


Figure 3.4 – Magnetization curve of the ferrite material

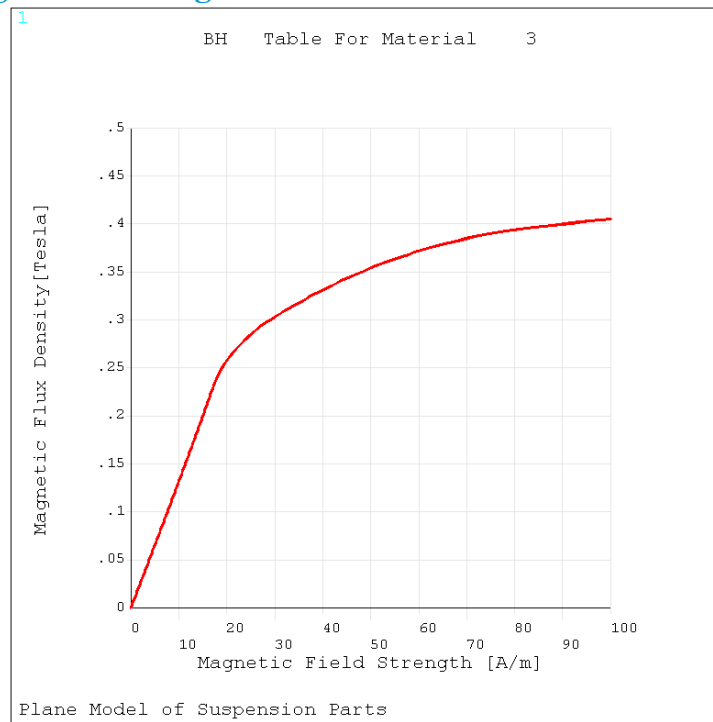


Figure 3.5 – Zoom in on the magnetization curve of the ferrite material, where the material starts to saturate

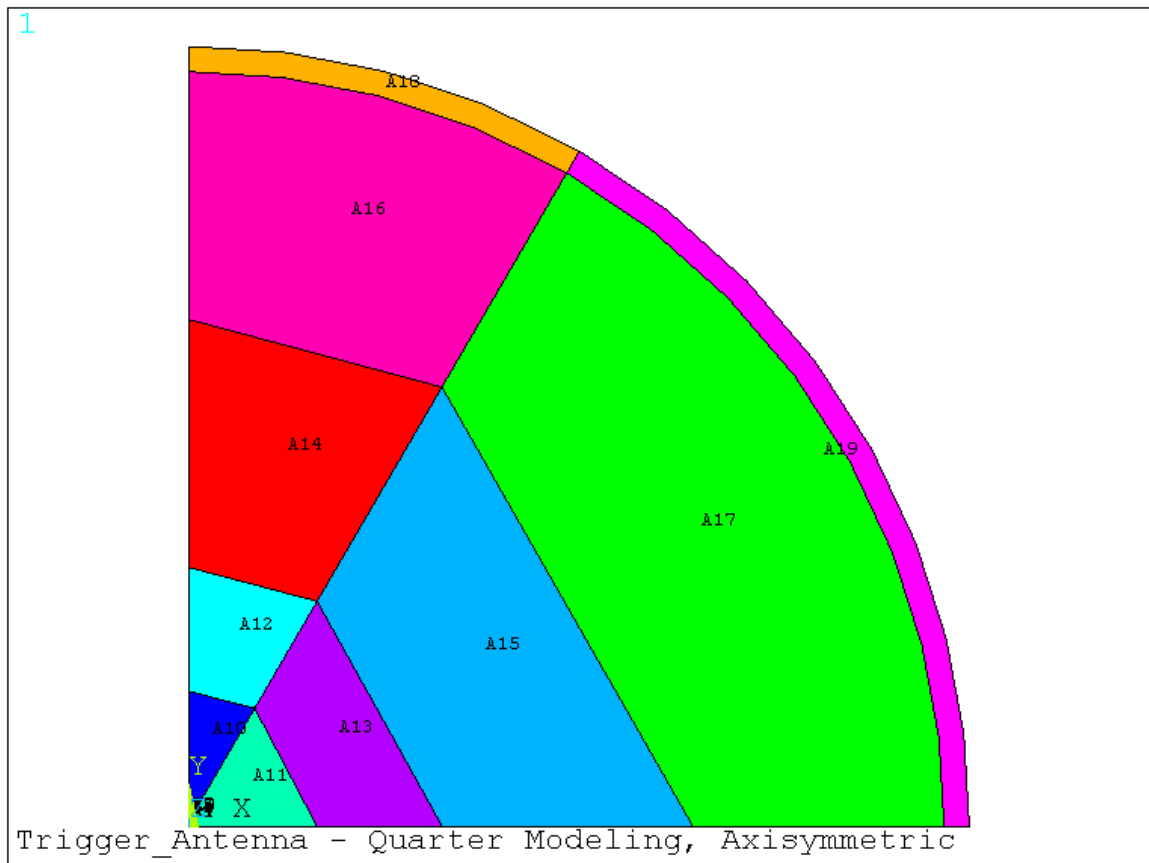
MPTEMP command defines a temperature table to be associated with the property data table [**MPDATA**]. In this simulation it is used as a default command, that is no temperature table is defined and the properties must be input as a constant or linear function of temperature with the **MP** command.



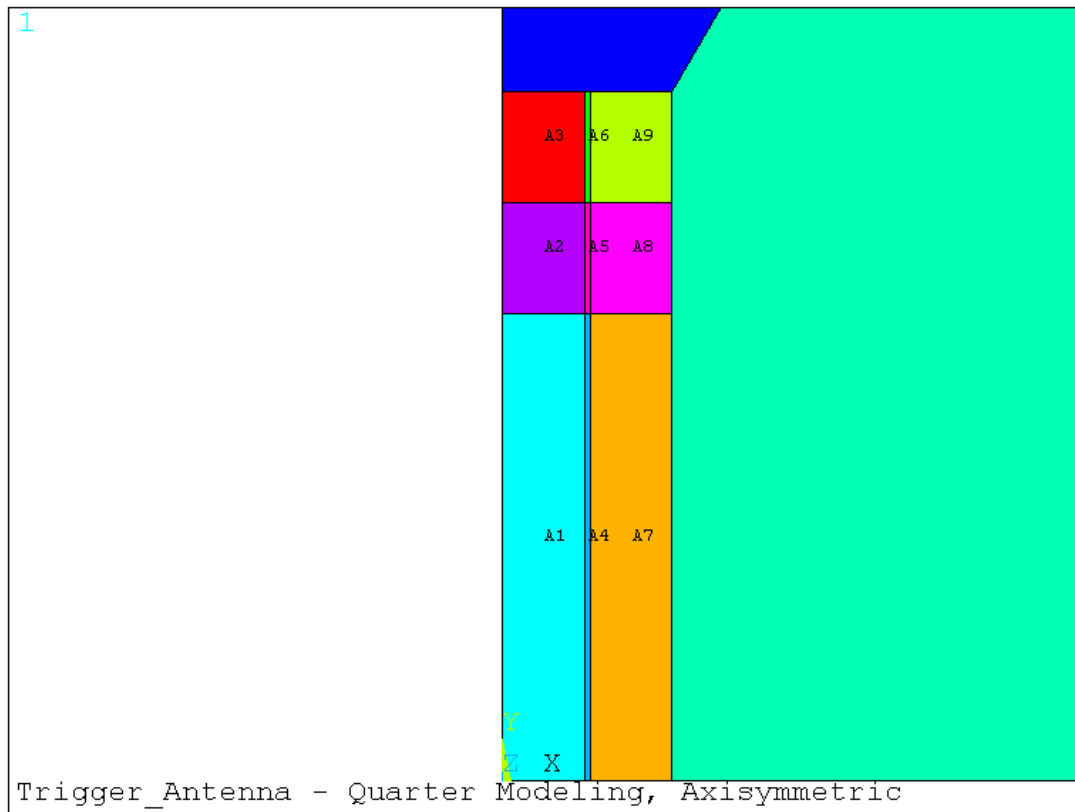
MPDATA defines a table of property data to be associated with the temperature table, in this case electrical resistivities in x-direction (RSVX) for air, copper, and ferrite.

The **TB** command activates a data table, magnetic field data (BH), for nonlinear material properties. This B versus H curve was taken out from the datasheet of the ferrite core and its values were defined using the **TBPT** command.

The model was created from the bottom up, which means that keypoints were first created, using **K** command, and these keypoints are used to define higher-order solid model entities (lines, areas, and volumes – for 3-D modelling), using commands like **LSTR**, **CIRCLE**, **AL** (**Figure 3.6**). The Keypoints are the lowest-order solid model entities and are defined within the currently active coordinate system.



(a) View over all the areas



(b) Zoom in on the antenna areas (A1, A2, A4)

Figure 3.6 – Area plot, representing the ferrite core (A1, A2), the copper coil (A4) and air (A3, A5, ..., A19)

Boolean algebra provides a means for combining *sets* of data, using such logical operators as intersect, union, subtract, etc. The ANSYS program allows to apply these same Boolean operators to the solid model, so that the solid model constructions can be modified more easily.

Some of these Boolean operations are realized in this simulation by using the following commands: **LDIV** (divides lines into two or more lines, according to the specified options), **LCOMB** (combines adjacent lines into one line), **LSBL** (subtracts lines from lines).

```
K, ,r,l/2,,
K, ,-r,l/2,,
K, ,-r,-l/2,,
K, ,r,-l/2,,
LSTR, 1, 2
LSTR, 2, 3
LSTR, 3, 4
LSTR, 4, 1
!
LDIV,21, , ,3,0
```



```

!
FLST,2,2,4,ORDE,2
FITEM,2,93
FITEM,2,45
LCOMB,P51X, ,0
!
FLST,2,1,4,ORDE,1
FITEM,2,2
FLST,3,1,4,ORDE,1
FITEM,3,20
LSBL,P51X,P51X, ,DELETE,KEEP

```

In order to mesh the solid model, the lines were divided into proper dimensions for a dense mesh, using the [LESIZE](#) command.

```

FLST,5,2,4,ORDE,2
FITEM,5,76
FITEM,5,80
CM,_Y,LINE
LSEL, , , ,P51X
CM,_Y1,LINE
CMSEL, ,,_Y
!*
LESIZE,_Y1, , ,40,1, , , ,1

```

Element attributes were assigned to areas before meshing, using the [AATT](#) command. Using the [TYPE](#) command, a pointer was created to the element attributes specifying which of the three defined elements (first [PLANE53](#), the second [PLANE53](#), or [INFIN110](#)) should be used for the areas to be meshed. Area A4 is the copper coil, areas A1 and A2 are the ferrite core and areas A3, A5, ..., A19 are air. The [MSHAPE](#) command was used to specify the dimension of the model to be meshed (2D) and to specify the element shape to be used (quadrilateral-shaped elements). For meshing the areas, it was used the [MSHKEY](#) command with the option of free meshing in this simulation, because the mapped meshing is not possible everywhere. If the keyoption of using mapped mesh where possible and free mesh where mapped mesh is not possible is active, then the SmartSizing is turned off. This means that the [LESIZE](#) command has no effect anymore, and the software takes control over the divisions of the lines and does the mesh by itself. **Figure 3.7** illustrates the resulted elements after free meshing.

```

FLST,5,3,5,ORDE,3
FITEM,5,51
FITEM,5,54
FITEM,5,57
ASEL,S, , ,P51X
AATT,3
TYPE,3

```



```
MSHAPE,0,2D
MSHKEY,0
AMESH,ALL
```

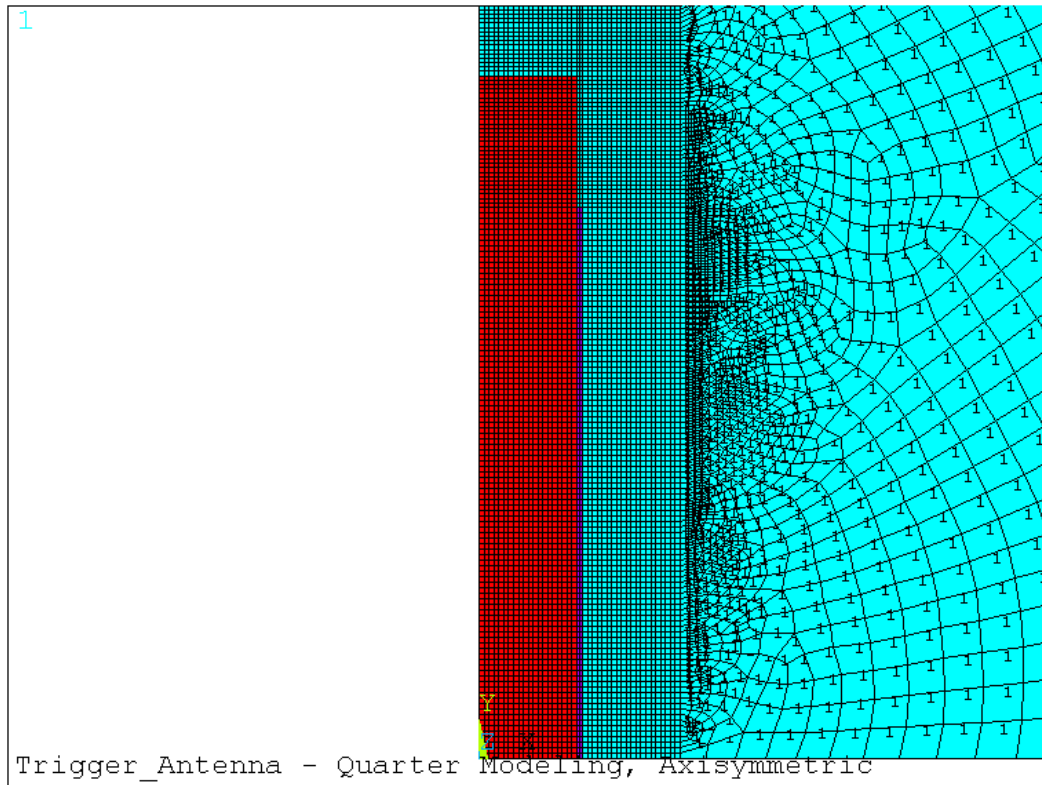


Figure 3.7 – Elements resulted after meshing the areas

Elements 1, shown in blue color, represent the air. Elements 2, shown in purple color, represent the copper coil wound around the ferrite core. The ferrite core is shown in red color, elements 3. This figure is just a zoom in made on the antenna. Without the zoom, it's impossible to see the antenna because of the big air area represented around it.

The infinite elements situated at the exterior of the model were flagged using the **SF** command, for modelling the far field.

Nodes in the coil area A4 were all coupled to a set with the degree of freedom VOLT, using the **CP** command. Coupling degrees of freedom into a set causes the results calculated for one member of the set to be the same for all members of the set. Coupling the nodes using the VOLT degree of freedom indicate the fact that there is a current-fed massive conductor.

The flux lines are parallel with y axis and have a normal direction on x axis. The software recognizes by itself the normal flux condition, but the parallel flux lines condition had to be specified, using the **D** command.

```
CSYS,1
NSEL,S,LOC,X,r2
SF,ALL,INF
```




```
!
ESEL,S,MAT,,2
EPLT
NSLE
NPLT
CP,1,VOLT,ALL
!
CSYS,0
NSEL,S,LOC,X,0
D,ALL,AZ,0
```

Next step was to apply the loads on the model and solving it using the SOLUTION processor. The load in this simulation is the current and using the **F** command, it was applied to the coil. This current represents the total flow through the coil and it is calculated as the number of turns multiplied by the current on one turn. It was applied to only one node randomly picked up from the coil, because all the nodes belonging to the coil get the same value, as stated above.

```
FLST,2,1,1,ORDE,1
FITEM,2,8360
!*
/GO
F,P51X,AMPS,n*ip
```

Figure 3.8 shows the model after applying all the conditions: in red line, the exterior nodes set up for the infinite elements conditions, in purple color, the parallel flux condition on nodes situated on y axis, in green color, coil nodes coupled in a set, and the black arrow indicates the current applied to one node of the coil.

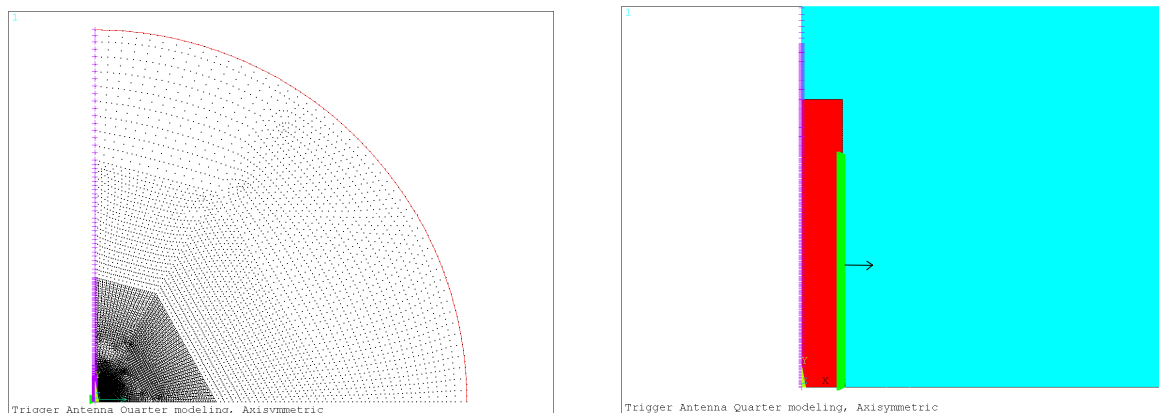


Figure 3.8 – Applied loads and boundary conditions

The type of the analysis is harmonic, defined by the **ANTYPE** command. Frequency was established by the **HARFRQ** command on 125 KHz. The **SOLVE** command was issued for solving the model. No additional substeps were specified (the



default **NSUBST** command) and ramped loading within a load step was specified by **KBC** command. This means that the loads are linearly interpolated (ramped) for each substep from the values of the previous load step to the values of this load step.

```
ANTYPE,3
HARFRQ,125000,0,
NSUBST,,
KBC,0
SOLVE
```

POST1 is the postprocessor used to view the results. By solving the model, the result files are being created. The database contains the geometry model, and now the first data set is read from the result files into the database by using the **SET** command. In **Figure 3.9** and **Figure 3.10** the flux lines, plotted by the **PLF2D** command, can be noticed.

```
/POST1
SET,FIRST
PLF2D,60,0,10,1
```

The shape of the flux lines is similar to that of a dipole. Therefore a magnetic field was created around the ferrite core by the current flowing through the copper windings.

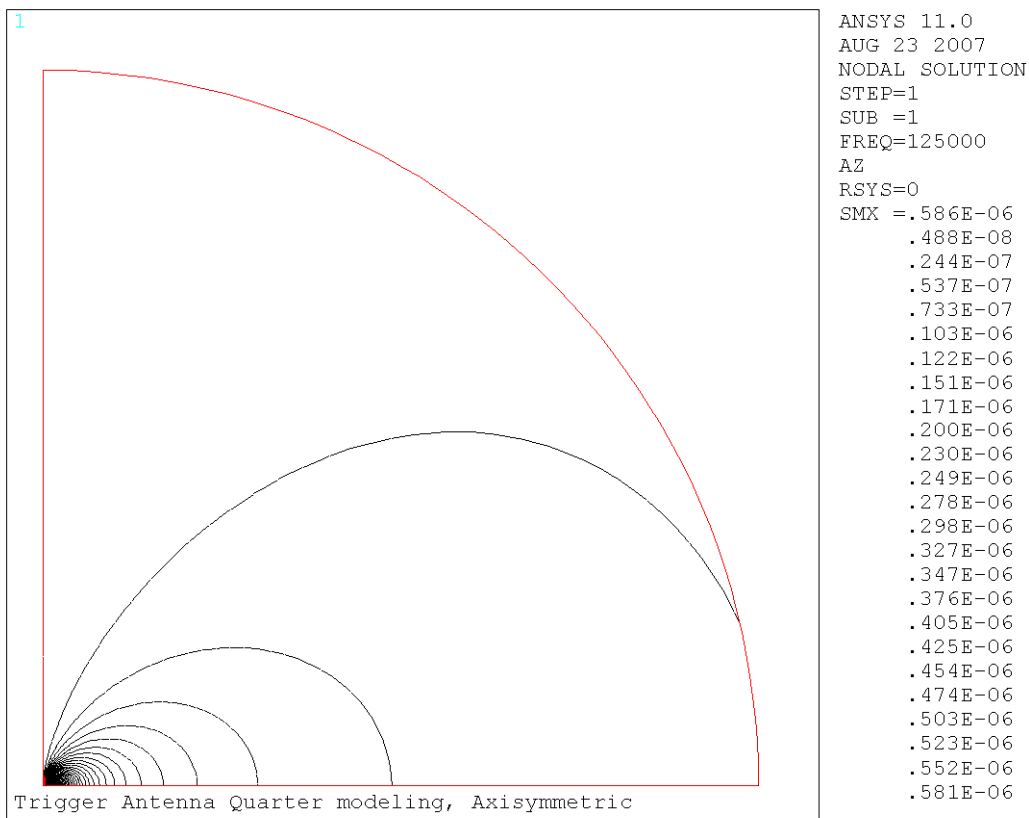


Figure 3.9 – Flux lines of the triggering antenna

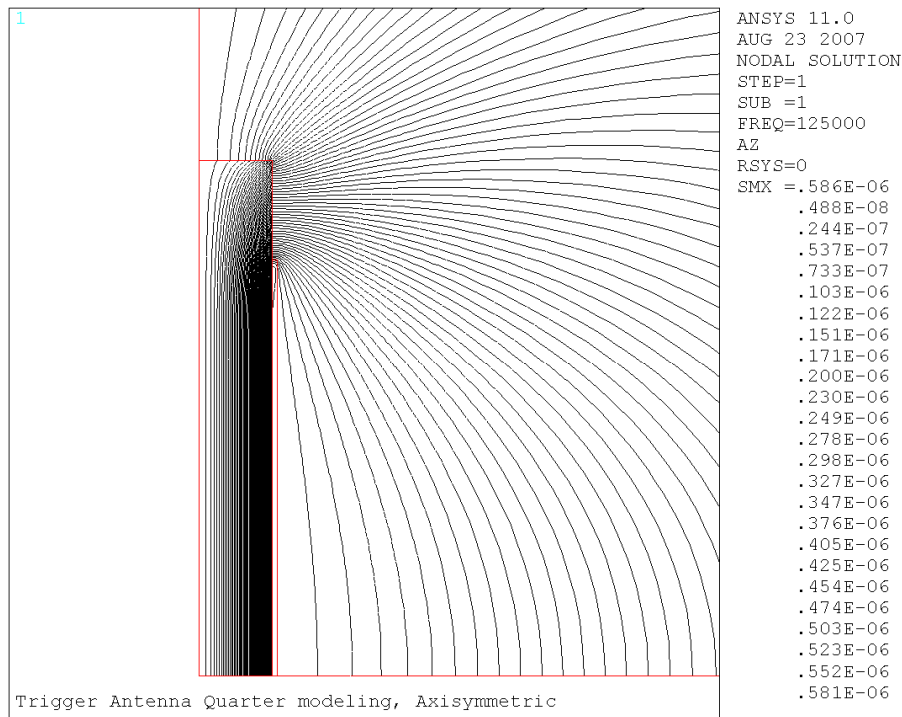


Figure 3.10 – Flux lines of the triggering antenna, zoom on the antenna

If the flux lines are plotted using symmetry expansion, it is obvious that this antenna acts like a magnetic dipole (**Figure 3.11**).

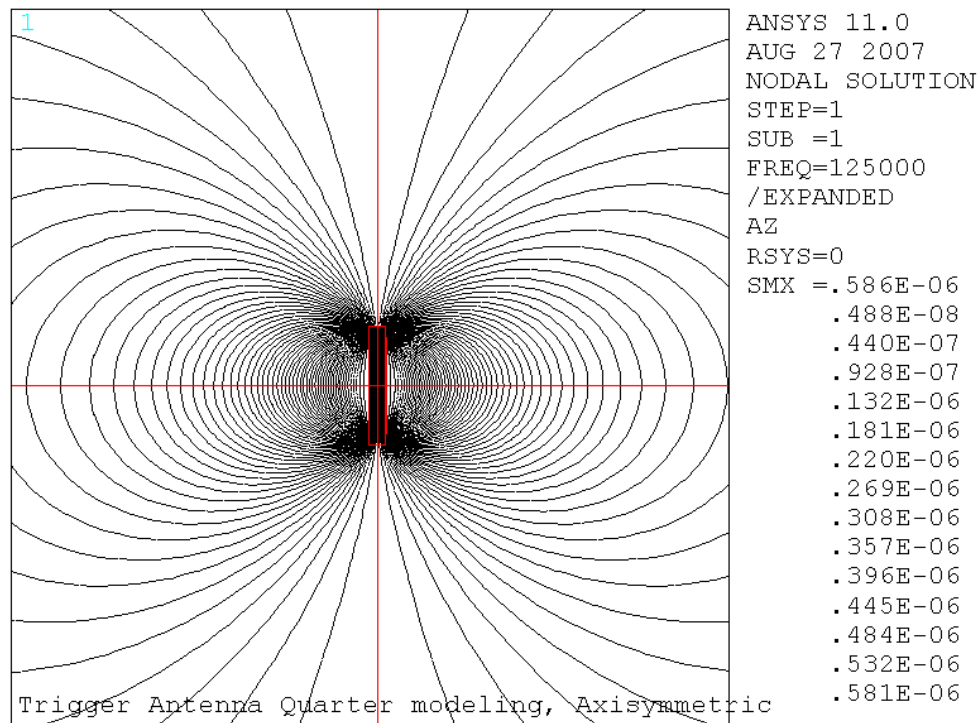


Figure 3.11 – Flux lines of the triggering antenna, symmetry expansion



The magnetic flux density vector sum was plotted (**Figure 3.12**). After measuring the field density in the laboratory, a comparison can be made to check if the results match.

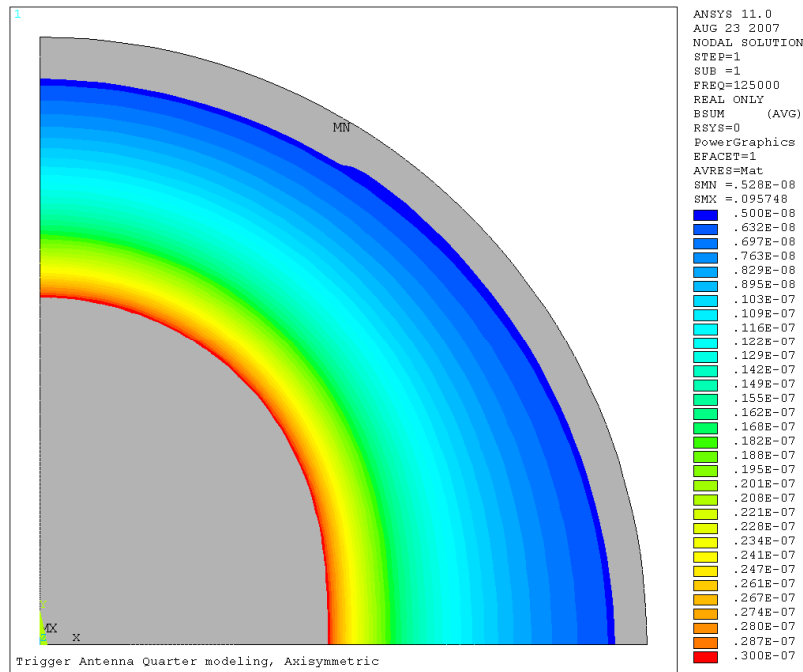


Figure 3.12 – Magnetic flux density in the air surrounding the antenna

After plotting the field density in the ferrite core, it can be noticed that this doesn't get higher values than 2T. It has a value of 0.14 ~ 0.15T in the middle of the core, rising up to 1.9T at the ends (**Figure 3.13**).

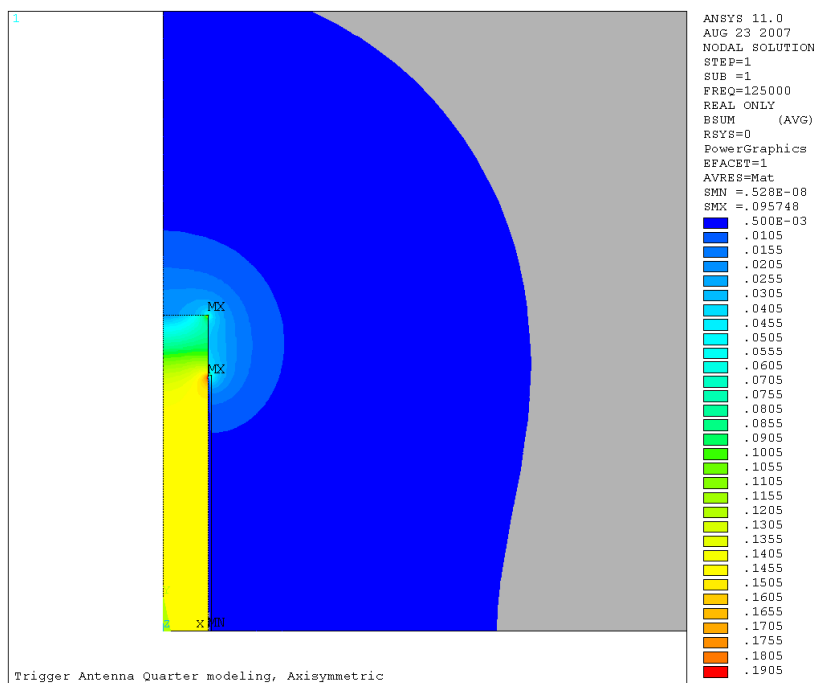


Figure 3.13 – Magnetic flux density in the ferrite core



Magnetic field intensity can be also checked for corresponding with the real values (**Figure 3.14**). In the middle of the core, it has a value of approximate 13A/m.

These are proofs that the simulation was right and that the antenna is working properly.

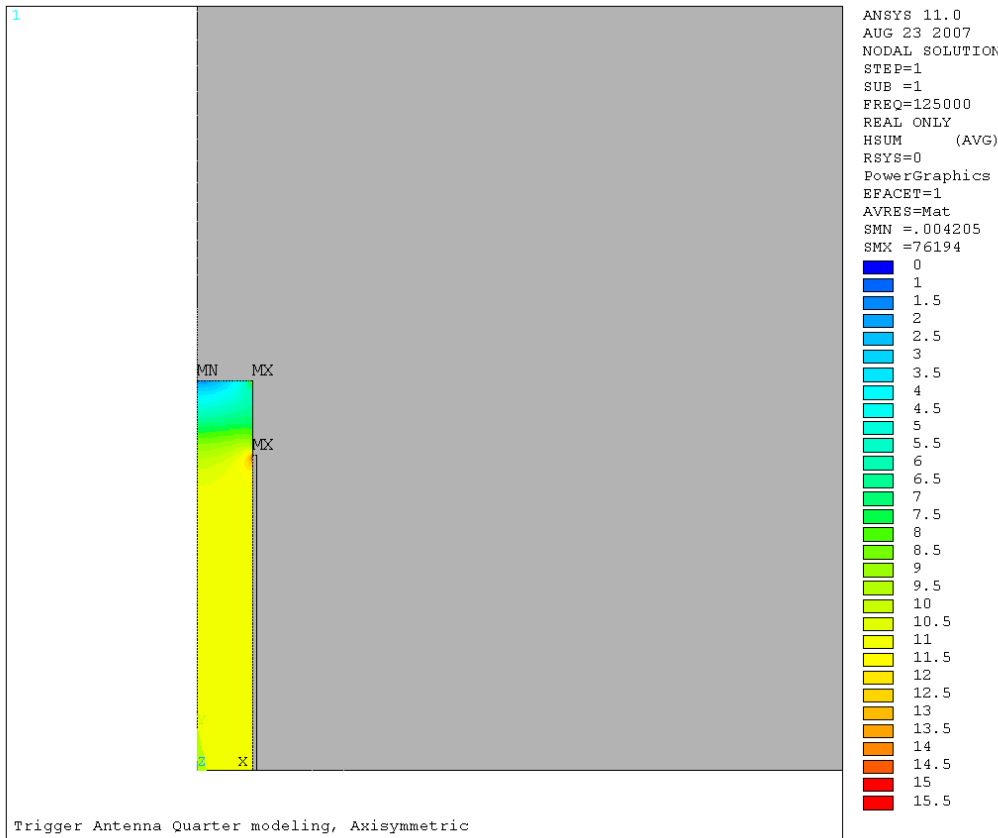


Figure 3.14 – Magnetic flux intensity in the ferrite core

Next step in the simulations was to add the suspensions part and see the influence of the magnetic field over them. The magnetic field creates eddy currents which flow through the metal parts of the car and create secondary magnetic fields. This secondary field can trigger the electronic part in the opposite wheel of the car and this is where from a bad malfunctioning of the system occurs. Modelling the suspension parts of the car implies no kind of symmetry, because there is no possibility of having symmetry. Therefore planar modelling is used for this simulation, and this introduces numeric errors because the model is assumed to be infinite over the z axis, which in reality is not like that, the suspensions parts have defined finite dimensions.

A planar model representing only the triggering antenna was first created to compare it with the symmetric model. The numeric results are not the proper ones, but now we are interested in the quality of the simulation. **Figure 3.15** shows the magnetic field density around the coil.

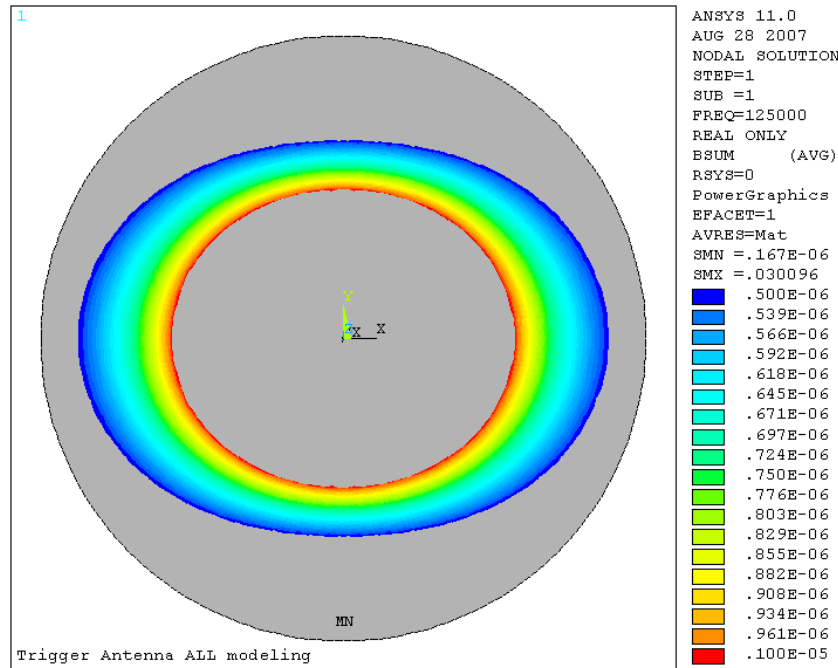


Figure 3.15 – Magnetic flux density

The command lines in the program are not to be discussed from now on, because the procedure of designing and building the models for the simulations is similar to the first one described. For more details about the scripts, please refer to Annex 2.

Now we can introduce the suspensions parts and see the changes over the magnetic field density and their influence.

Suspension parts modelled belong to a BMW 3 series. There is no real problem in the car, because there are isolation materials inserted between the parts which form the suspension. This can be seen further on in the simulations. The purpose of modelling is to get the feeling of the magnetic field in the car and to be able to state what would be proper for using in the suspension parts to reduce the crosstalk.

The second simulation starts by defining some new parameters for the dimensions of the suspension parts. The suspension parts are made out of aluminium and/or steel, so material properties must be defined also.

```
*SET,aluminium,2.72e-8
*SET,al,2.82e-8
*SET,g1,4e-2
*SET,g2,1e-2
*SET,g3,9e-2
*SET,g4,14e-2
*SET,g5,8e-2
*SET,g6,1.5e-2
*SET,a,27.5e-2
*SET,b,3.75e-2
```



```

*SET,c,22e-2
*SET,e,84e-2
*SET,f,8e-2
*SET,d,36e-2
*SET,h,2.5e-2
*SET,i,68e-2
!
MPTEMP,,,,,,,,
MPTEMP,1,0
MPDATA,MURX,4,,1000
MPDATA,RSVX,4,,aluminium
!
MPTEMP,,,,,,,,
MPTEMP,1,0
MPDATA,MURX,4,,10000
MPDATA,RSVX,4,,steel

```

New areas representing the suspensions parts were built (**Figure 3.16**)

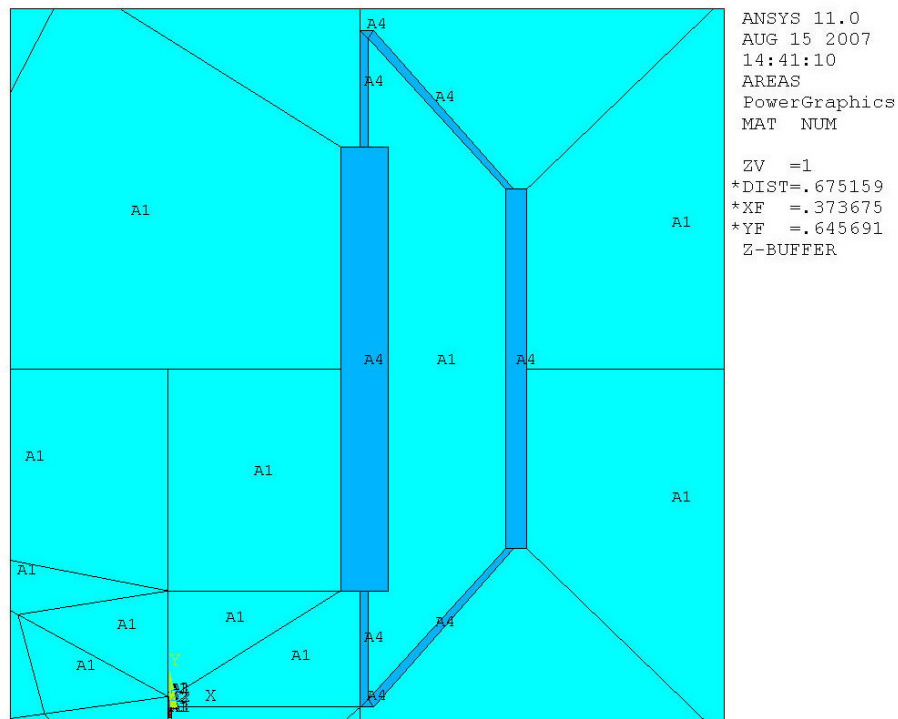


Figure 3.16 – Suspensions part

The loads, the coupling degrees of freedom (DOF) were applied as before. After plotting the flux lines, it can be noticed how they are distributed around the suspension parts (**Figure 3.17**)

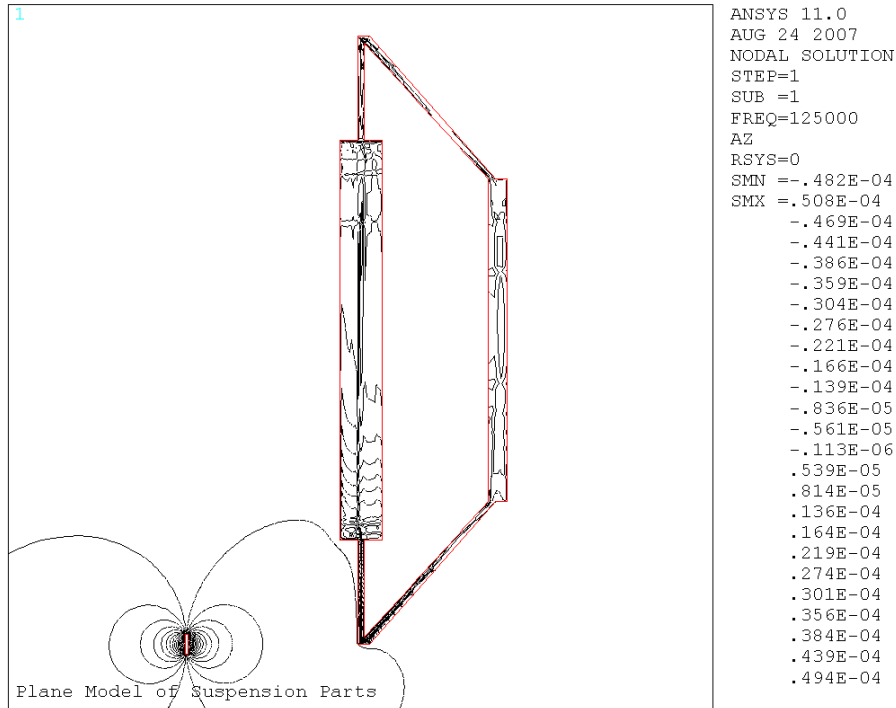


Figure 3.17 – Flux lines on suspensions part

On **Figure 3.18** it can be noticed how the eddy currents from the suspension parts create secondary magnetic field, opposing the initial one.

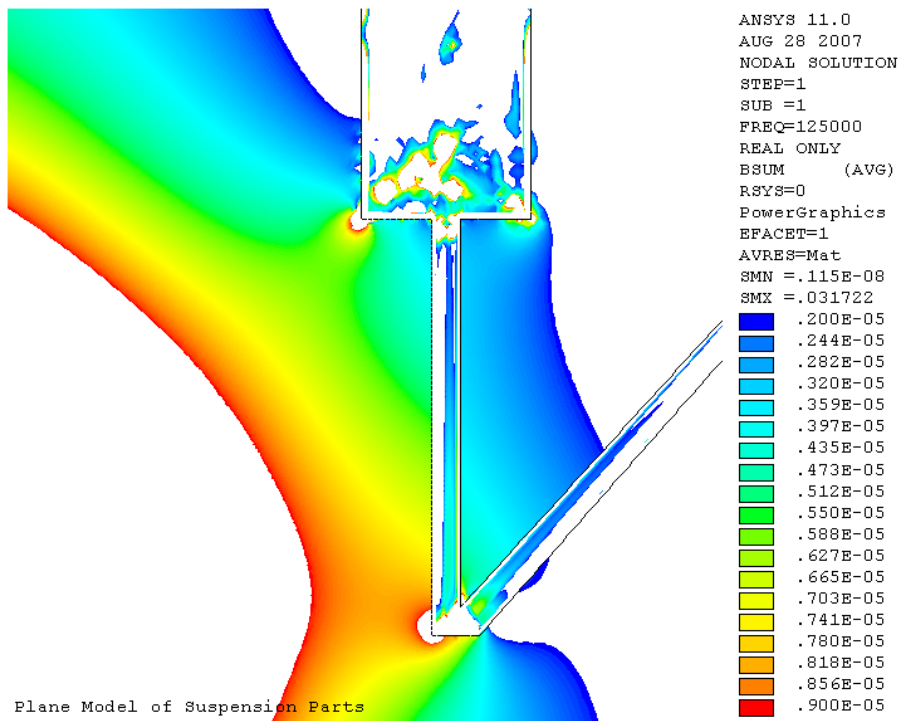


Figure 3.18 – Secondary magnetic field opposing the initial one



On the other end of the suspension parts, it can be noticed the second magnetic field as well (**Figure 3.19**), which determines the crosstalking.

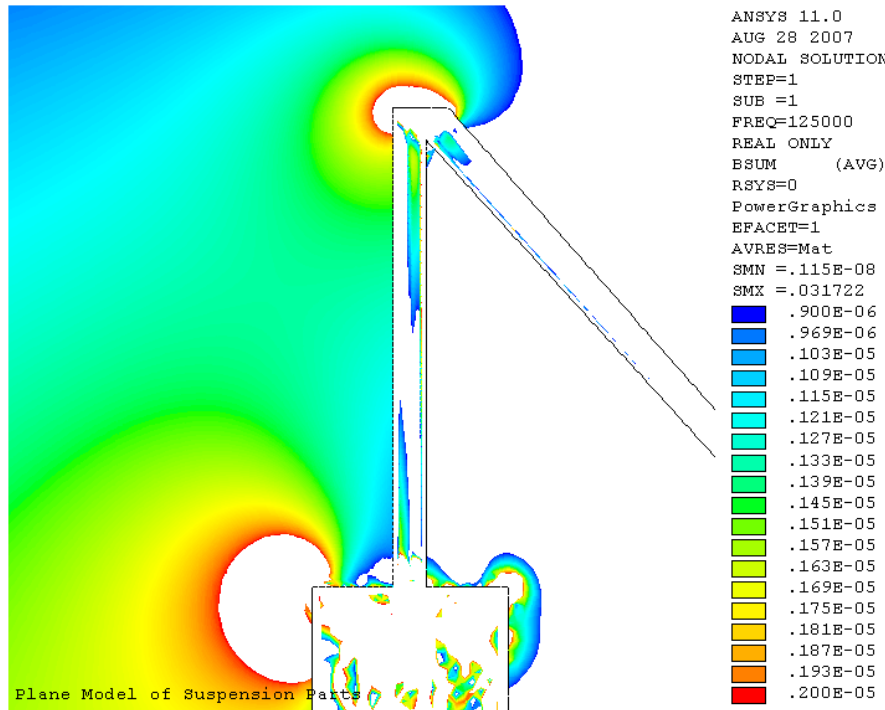


Figure 3.19 – Secondary magnetic field on the opposite wheel

Looking through the whole suspensions parts, we can see the continuous magnetic field induced by the eddy currents (**Figure 3.20**). If there are isolation materials, like rubber, between the metal parts of the car, the eddy currents do not flow in a closed loop and the magnetic field created on the opposite wheel is decreased (**Figure 3.21**).

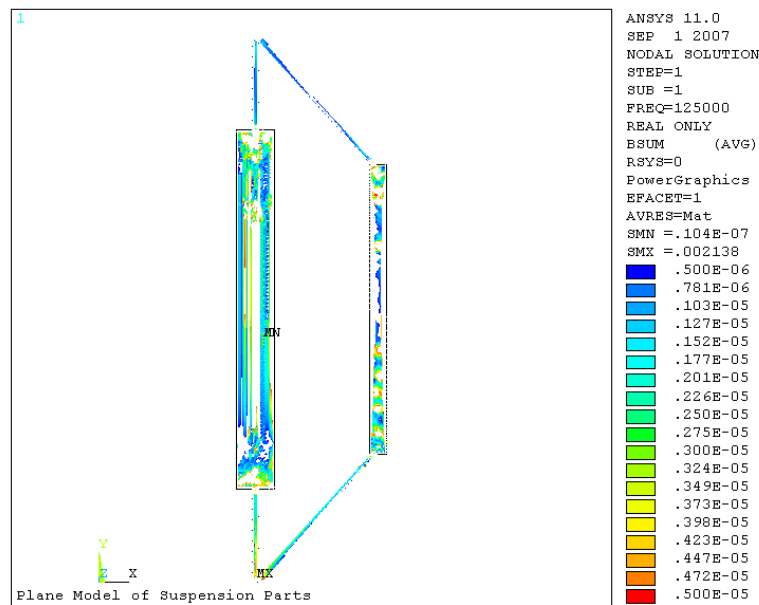


Figure 3.20 – Magnetic field in the suspension parts

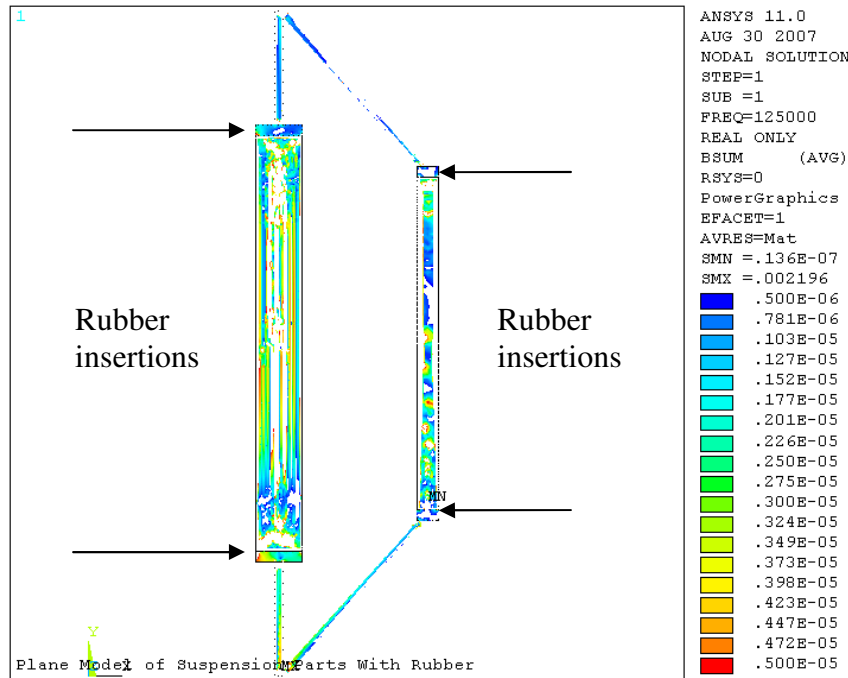


Figure 3.21 – Magnetic field in the suspension parts isolated by rubber

Another approach of this project was to see how the magnetic field changes with the distance between the triggering antenna and the suspension parts, along the x axis and the y axis. To achieve the right results in this way, a series of simulations were created, starting with a 10 cm distance along the x axis (**Figure 3.22**) up to 50 cm distance (**Figure 3.23**) between the antenna and the suspensions.

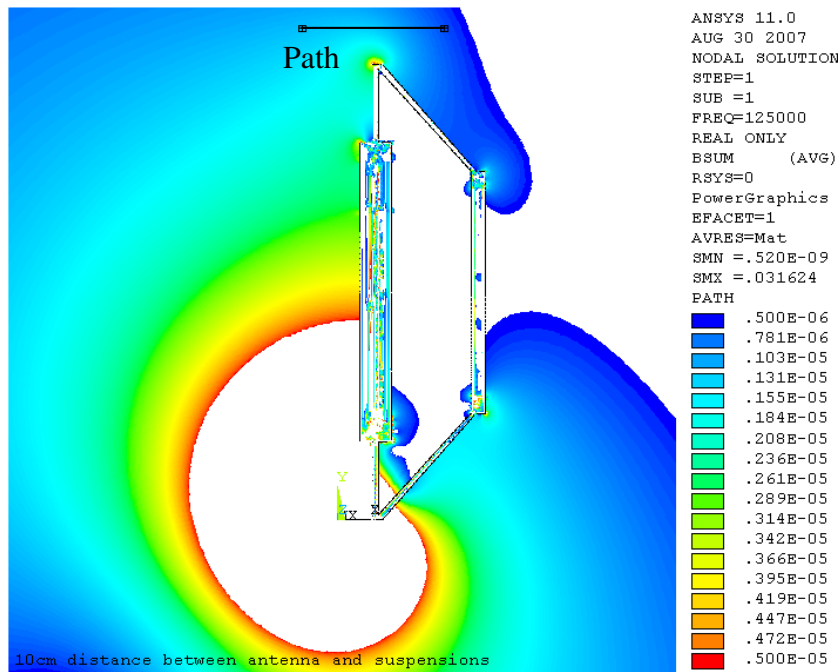


Figure 3.22 – 10cm distance on x axis between the trigger sender and suspensions

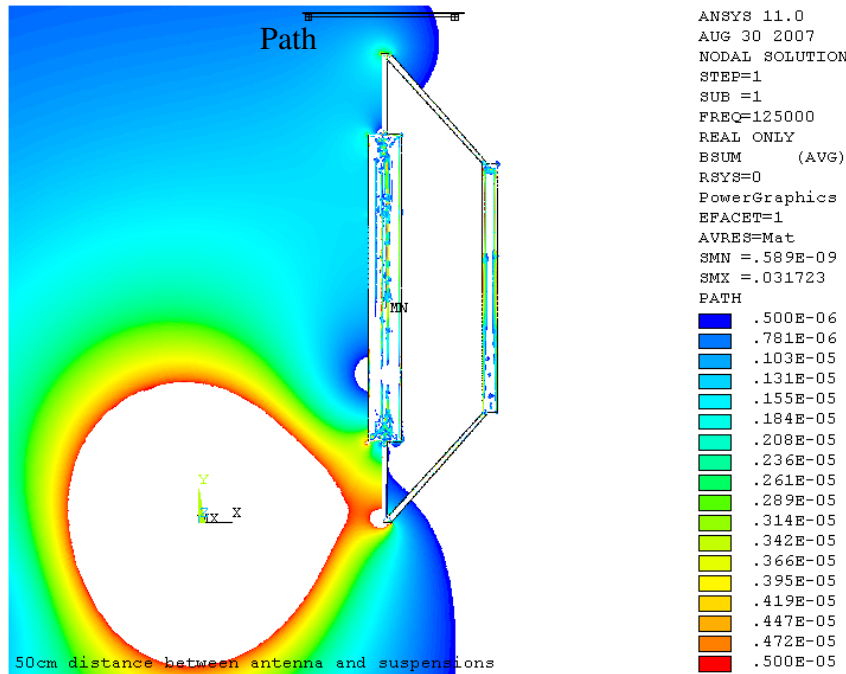


Figure 3.23 – 50cm distance on x axis between the trigger sender and suspensions

The same simulations were done moving the suspension parts along the y axis, from 10 to 40 cm. It can be seen in **Figure 3.24** that there is not much influence of the magnetic field if the parts are being moved far enough, so there is no crosstalking anymore. This method of reducing the field strength cannot be efficient in reality because the trigger sender unit it's situated in the wheel house and this means less distance along the y axis between it and the suspension parts.

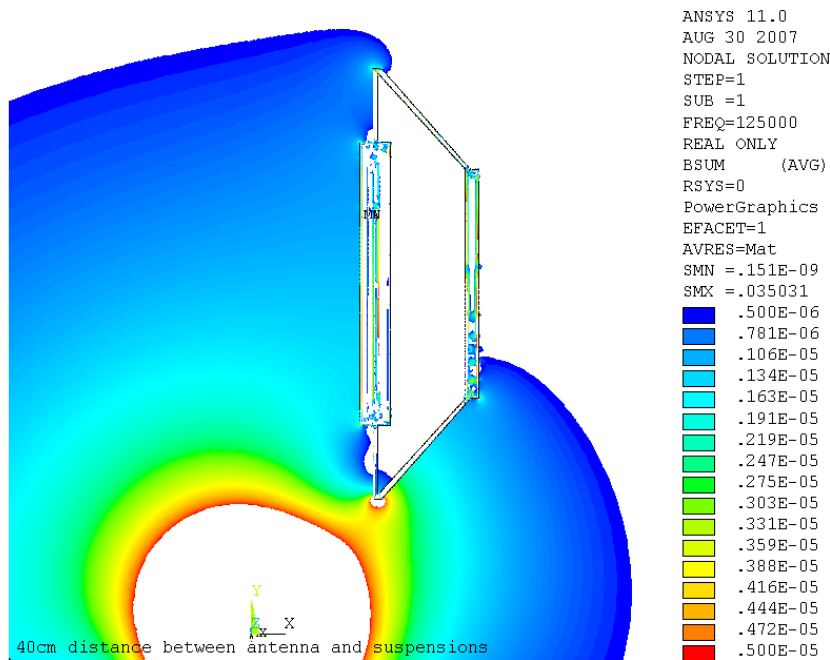


Figure 3.24 – 40cm distance on y axis between the trigger sender and suspensions



In reality, the trigger sender in the car can be situated anywhere in the wheel house, so there is also a moving along the z axis.

To check the mesh accuracy and the correctitude of the simulation, the properties of the whole suspension parts were changed as rubber. The simulations were right again, there is no influence over this type of materials, as it can be noticed in **Figure 3.25**.

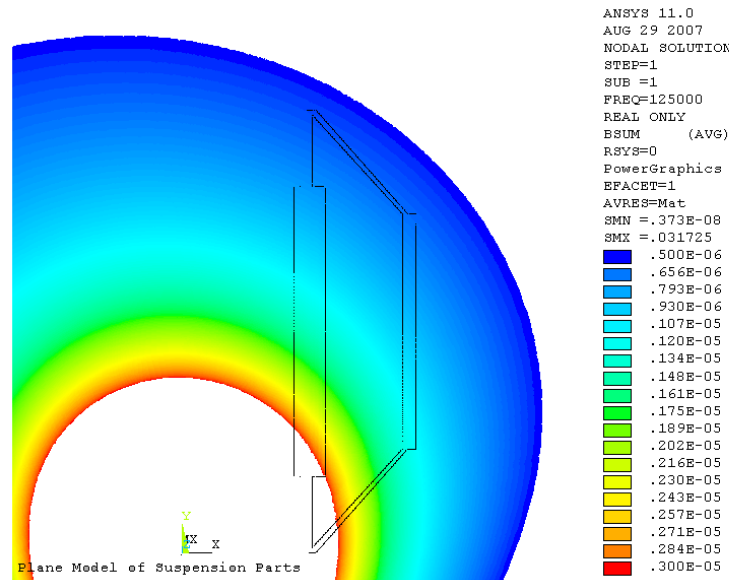


Figure 3.25 – Non-conductive material placed in the magnetic field

An interesting result to follow would be if the current applied to the coil is modified in such a way that the magnetic field has the real value around the trigger sender, at the wheel where it is triggered, path 'P1'. The values over the opposite wheel plotted on the 'P2' path in the **Figure 3.26** are taken out in a text file by ANSYS and compared later on with the results made in the tests.

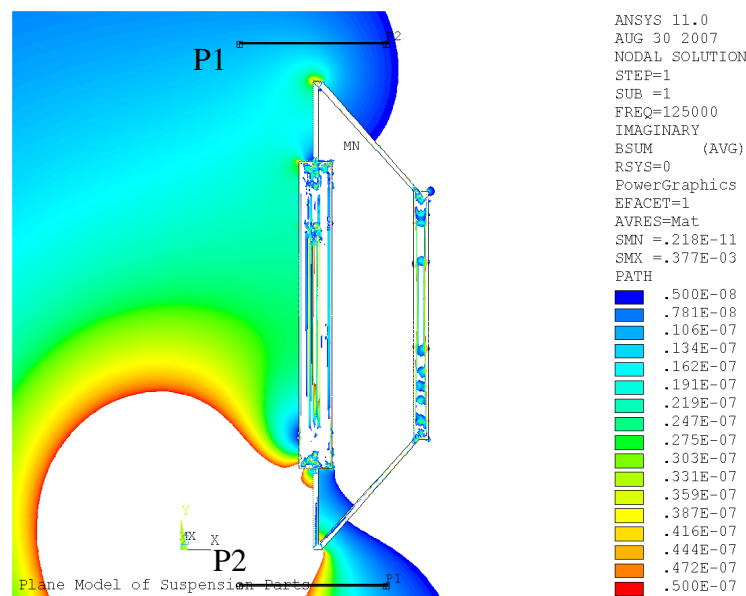


Figure 3.26 – Crosstalking determined on the opposite wheel



3.2.2. 3-D Modeling

3-D *SOLID* analysis models are used for thick structures in 3-D space that have neither a constant cross section nor an axis of symmetry. Creating a 3-D solid analysis model by direct generation methods usually requires considerable effort. Solid modeling will nearly always make the job easier.

The 3D approach requires much more hardware resources than the 2D approach for obtaining the same precision but it is preferable in the cases of nonsymmetrical configurations, like this project.

A 3-D model of the triggering antenna was created first, representing the eight part of it. Building the geometry and applying the loads are no longer described, as the method is similar to the 2-D one. For more information about the script of the simulation see Annex 2.

Figure 3.27 shows the geometry of this model.

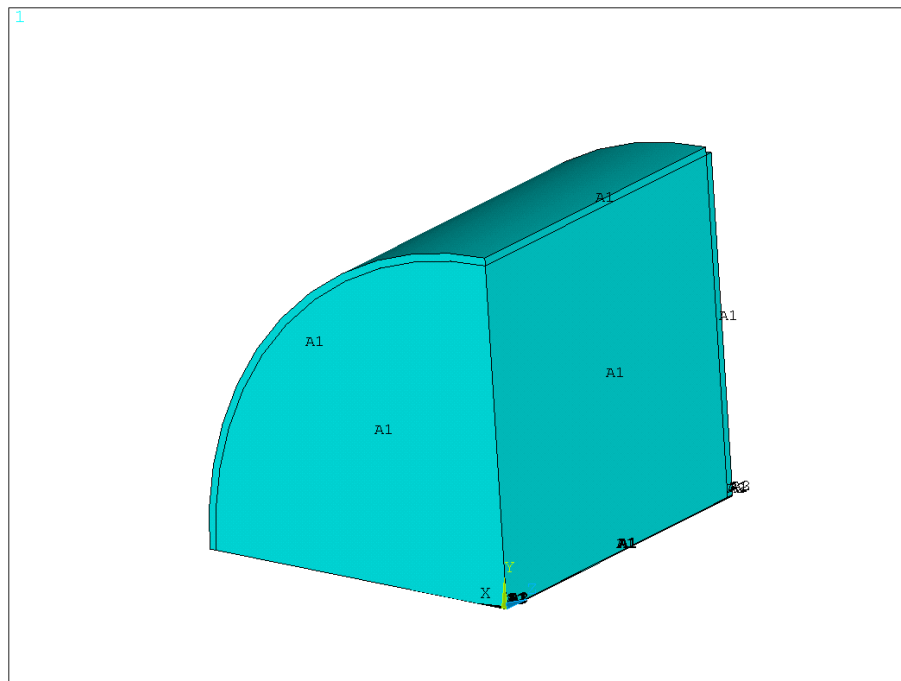


Figure 3.27 – 3-D model

Unfortunately, this simulation cannot be solved because of the huge number of equations (tens of millions). The trigger sender has very small dimensions comparing to the air surrounding it. A fine mesh is required for the antenna, increasing slowly to the exterior. Tri-dimensional modeling of this implies too many elements, therefore too many nodes where the software has to calculate values.



NOTE! ANSYS commands are written in **blue**, **bold** and **underlined** characters. ANSYS elements used for modeling are written in **blue** and **underlined** characters. For more information over all the commands mentioned and all the elements used in this paper see reference [1].



3.3. Experimental Work

Some triggering antennas need to be measured in order to compare the simulation results with the real values of the field. A frequency of approximate 125Khz triggers the antennas, the voltage is being read and by indirect method, the magnetic field intensity is determined. The measurements were done in the laboratory, using a Helmholtz coil and determining first the voltage induced in the Helmholtz coil by the magnetic field. The reference for the measurements is a known trigger sender. The value of the magnetic field created by this reference at a distance of 1 meter is measured with a probe. The Helmholtz coil gives the value of the voltage determined by this known reference trigger antenna. By comparing this data with the ones from the trigger senders which need to be measured, the magnetic field is indirectly calculated. The frequency is a few Hertz lower than the prescribed one because the trigger sender is mounted on a piece of metal, which increases the frequency up to 125Khz. The small value fluctuation from one trigger antenna to another is due to the tolerances of the different trigger senders.

Nr.	SerienNr.	Frequenz [kHz]	magn.	magn.
			Flussdicht e [Vpp]	Flussdicht e [nT]
1	50278000	123.0	6.53	8.46
2	50278001	122.2	6.63	8.59
3	50278002	122.0	6.63	8.59
4	50278003	122.2	6.59	8.53
5	50278004	122.2	6.56	8.49
6	50278005	121.3	6.59	8.53
7	50278006	121.6	6.59	8.53
8	50278007	122.7	6.56	8.49
9	50278008	121.6	6.50	8.42
10	50278009	123.4	6.47	8.38
11	50278010	123.6	6.63	8.59
12	50278011	121.8	6.63	8.59
13	50278012	121.7	6.69	8.66
14	50278013	123.0	6.50	8.42
15	50278014	123.3	6.66	8.62
16	50278015	122.7	6.56	8.49
17	50278016	122.2	6.75	8.74
18	50278017	122.3	6.56	8.49
19	50278018	122.2	6.63	8.59
20	50278019	122.8	6.66	8.62
21	50278020	121.9	6.63	8.59
22	50278021	121.5	6.66	8.62
23	50278022	122.9	6.56	8.49
24	50278023	122.3	6.63	8.59
25	50278024	122.3	6.63	8.59
26	50278025	121.3	6.63	8.59
27	50278026	122.9	6.44	8.34
28	50278027	122.2	6.50	8.42

Table 3.1 – Trigger sender measurements



This measurements need to be compared with the results of the simulation, in the 'Results' chapter of this project.

The second measurement was done on the car. An oscilloscope was connected to the wheel electronics' coil, and the voltage peak to peak in this coil was measured for several positions of the wheel. This voltage was introduced in a formula for indirect calculation of the magnetic field. The formula was obtained after a few measurements in the laboratory of some wheel electronics:

$$y = 8e^{-10} \cdot x^5 - 2e^{-7} \cdot x^4 + 3e^{-7} \cdot x^3 + 0.0008 \cdot x^2 + 0.4946 \cdot x - 0.5549$$

In the formula, y represents the B values, and x – the Vpp values.

Table 3.2 shows the results of the measured voltage and determined magnetic field in the wheel where the trigger sender is located.

Grad	Vpp [mV], min TS left rear	B [nT], min TS left rear	Threshold 6nT
0°	28.40	15.72	6.00
22.5°	26.80	14.80	6.00
45°	26.40	14.57	6.00
67.5°	23.60	12.97	6.00
90°	22.40	12.28	6.00
112.5°	23.20	12.74	6.00
135°	27.00	14.92	6.00
157.5°	32.80	18.24	6.00
180°	44.00	24.66	6.00
202.5°	41.60	23.28	6.00
225°	25.00	13.77	6.00
247.5°	202.00	115.19	6.00
270°	88.00	49.87	6.00
292.5°	11.20	5.86	6.00
315°	28.40	15.72	6.00
337.5°	31.20	17.32	6.00

Table 3.2 – Magnetic field strength in the wheel

Table 3.3 shows the crosstalking over the opposite wheel.

Grad	Vpp [mV], max TS right rear (Übersprechen)	B [nT], max TS right rear. (Übersprechen)	Threshold 4nT
0°	8.56	4.35	4.00
22.5°	7.84	3.94	4.00
45°	6.88	3.39	4.00
67.5°	6.00	2.88	4.00
90°	5.60	2.65	4.00
112.5°	4.88	2.24	4.00
135°	5.20	2.42	4.00
157.5°	4.80	2.20	4.00
180°	5.80	2.77	4.00
202.5°	7.80	3.91	4.00
225°	10.60	5.52	4.00
247.5°	12.20	6.44	4.00



270°	12.40	6.55	4.00
292.5°	12.00	6.32	4.00
315°	9.20	4.72	4.00
337.5°	10.00	5.17	4.00

Table 3.3 – Crosstalking on the opposite wheel

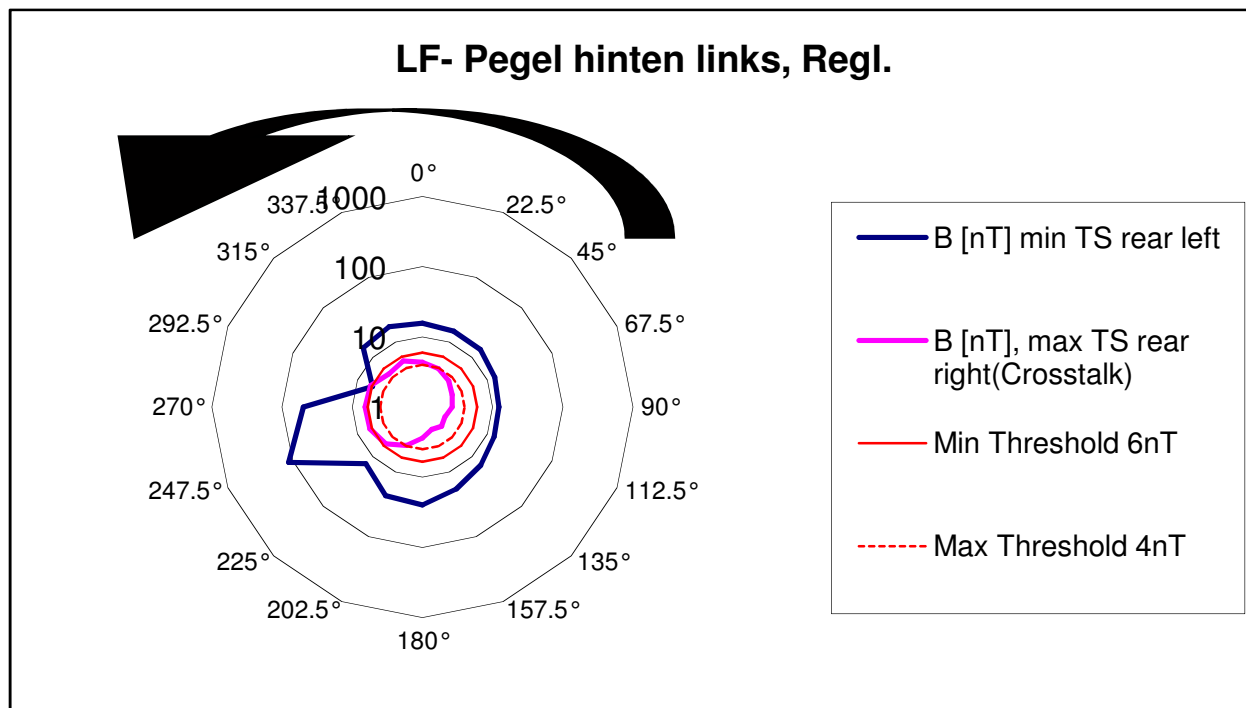
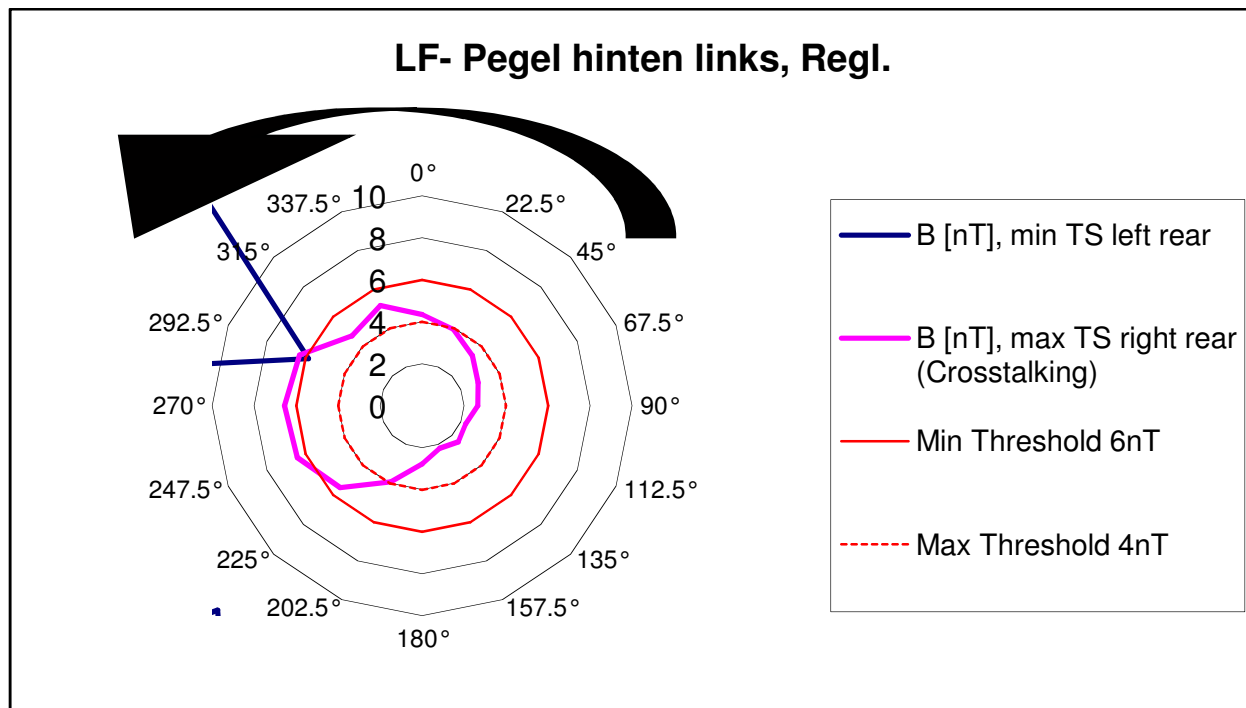


Figure 3.27 – Charts of the magnetic field values in the wheels



The blue line represents the values of the field on the rear left wheel and this values should not be smaller than the 6nT threshold because the trigger antenna cannot trigger its own electronic part.

The pink line represents the crosstalking over the opposite wheel. In case this values are higher than the 4nT threshold, then there is a crosstalking.

4

Results

Conclusions



Chapter IV

Results

Results from the simulation work are compared to results from experimental work. The magnetic field was plotted along the x axis, over the flux lines (**Figure 4.1**). This is the direction where the measurements were done. But it is interesting to be seen the values of the magnetic field, therefore the field values are plotted on a graph (**Figure 4.2**). The sudden drop of value is due to the difference of induction in the ferrite core and in the air. The ferrite has a 2.85mm radius which is very small comparing to the 1 meter distance where the magnetic field intensity is known, so it's necessary to scale the 1 meter area, to see the values as best as possible (**Figure 4.3**).

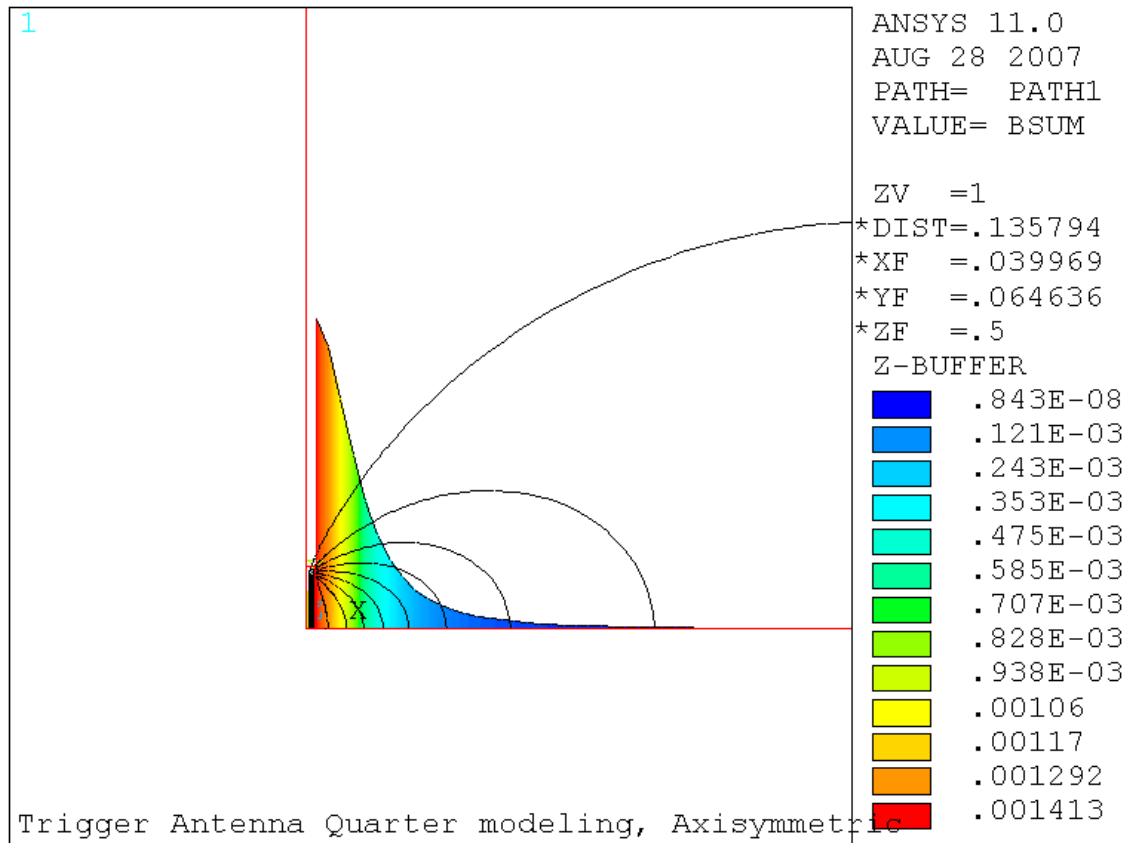


Figure 4.1 – Magnetic flux density along the x axis

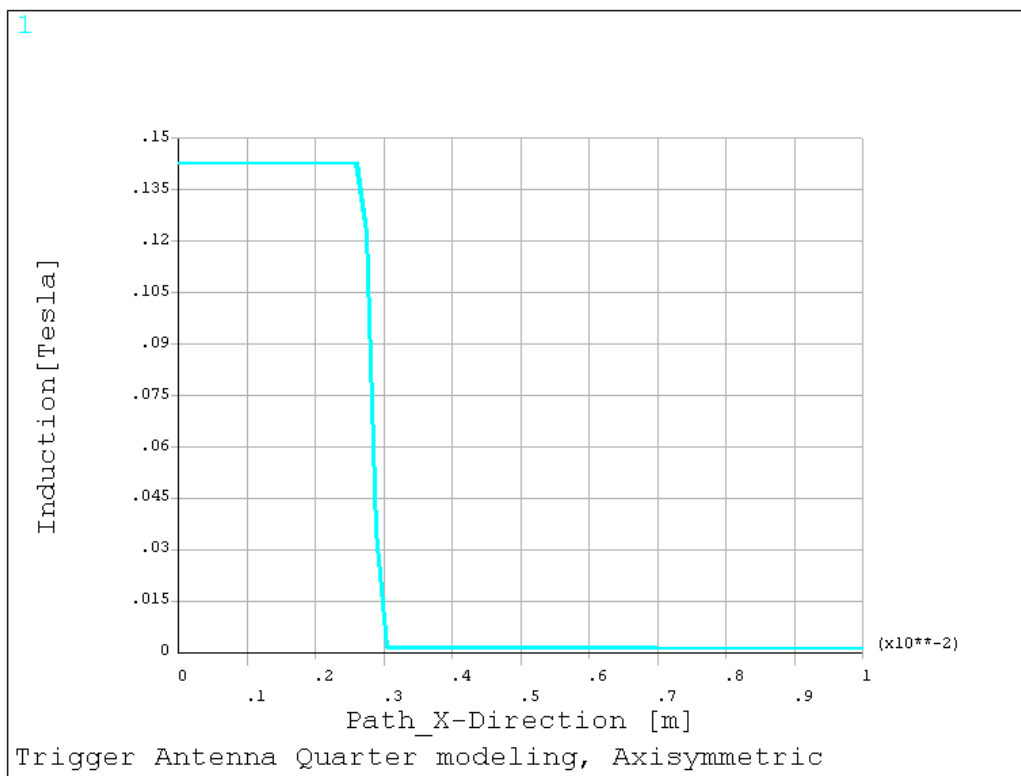


Figure 4.2 – Magnetic flux density along the x axis

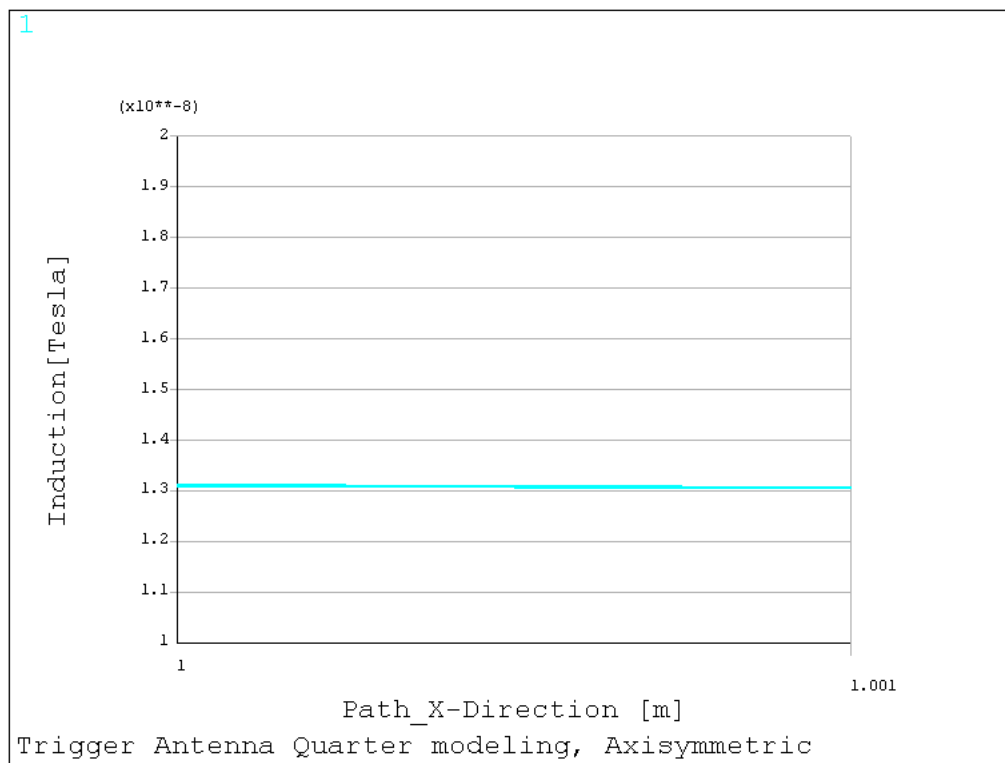


Figure 4.3 – Zoom on the x axis for the magnetic flux density



Simulation has given the result of approximate 13nT for the magnetic field intensity at 1 meter distance. Measurements for several triggering antennas revealed the results of 7.2 – 9nT. Now it can be stated that the simulation is correct, with a small difference that can be the result of geometry modelling or material properties. The ends of the ferrite core do not form a perfectly 90 degrees angle, but have in reality an angle of about 30 degrees. The magnetization curve introduced for the core was taken out from a graph in the datasheet, so the B and H values are approximate. These are two good reasons for the small difference between the simulation results and experimental results.

By introducing the suspension parts in the simulation, the numerical results change, because the geometry of the model does not allow any symmetry. The model has now infinite dimensions over the z axis and the current doesn't flow in a closed loop like it should be on finite dimension. The current flows along the z axis now and the insertion of the rubber material in the suspension parts doesn't have a big influence over the magnetic field induced in the surrounding air. Making a chart (**Figure 4.4**) can help to see the difference, but in the simulation this difference is too small in numerical values (**Figure 4.5**). In reality, this difference is higher because the currents flowing in the suspension plane are isolated by the rubber parts.

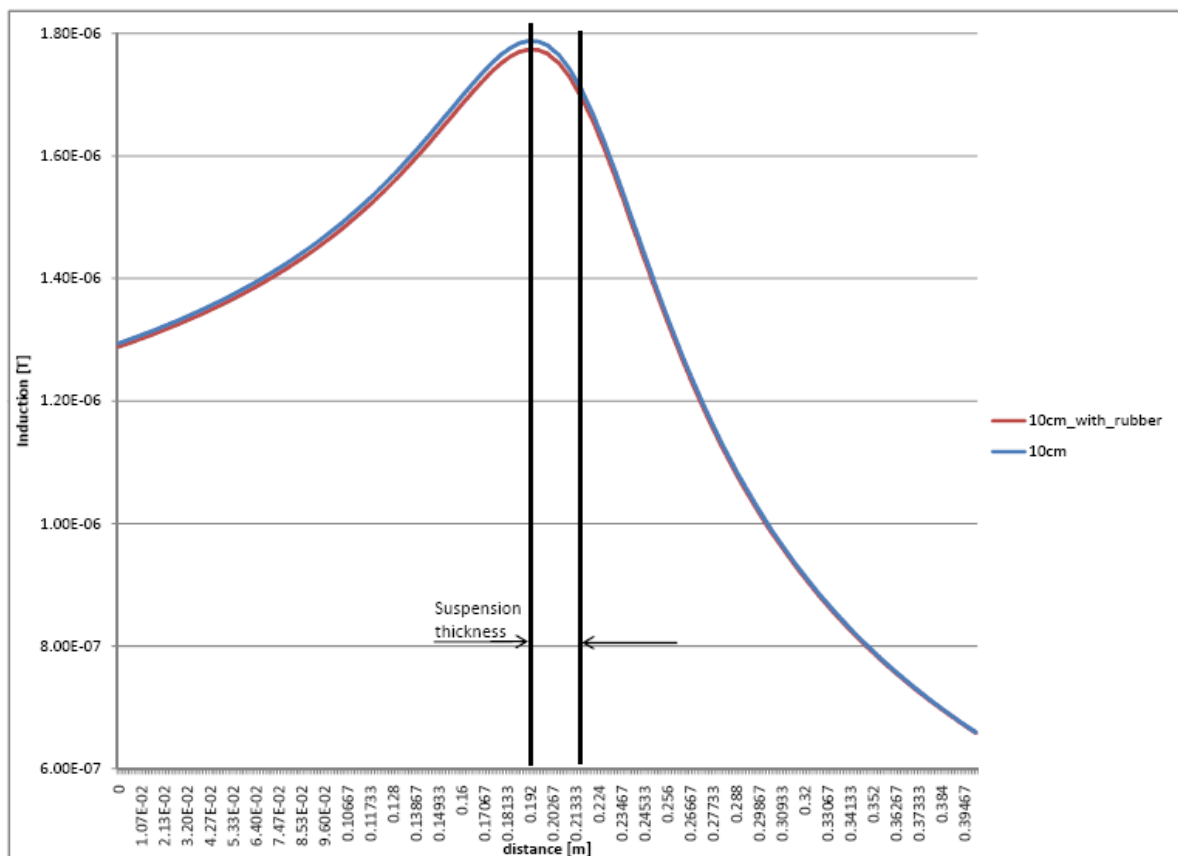


Figure 4.4 – Magnetic field values with and without the rubber insertions

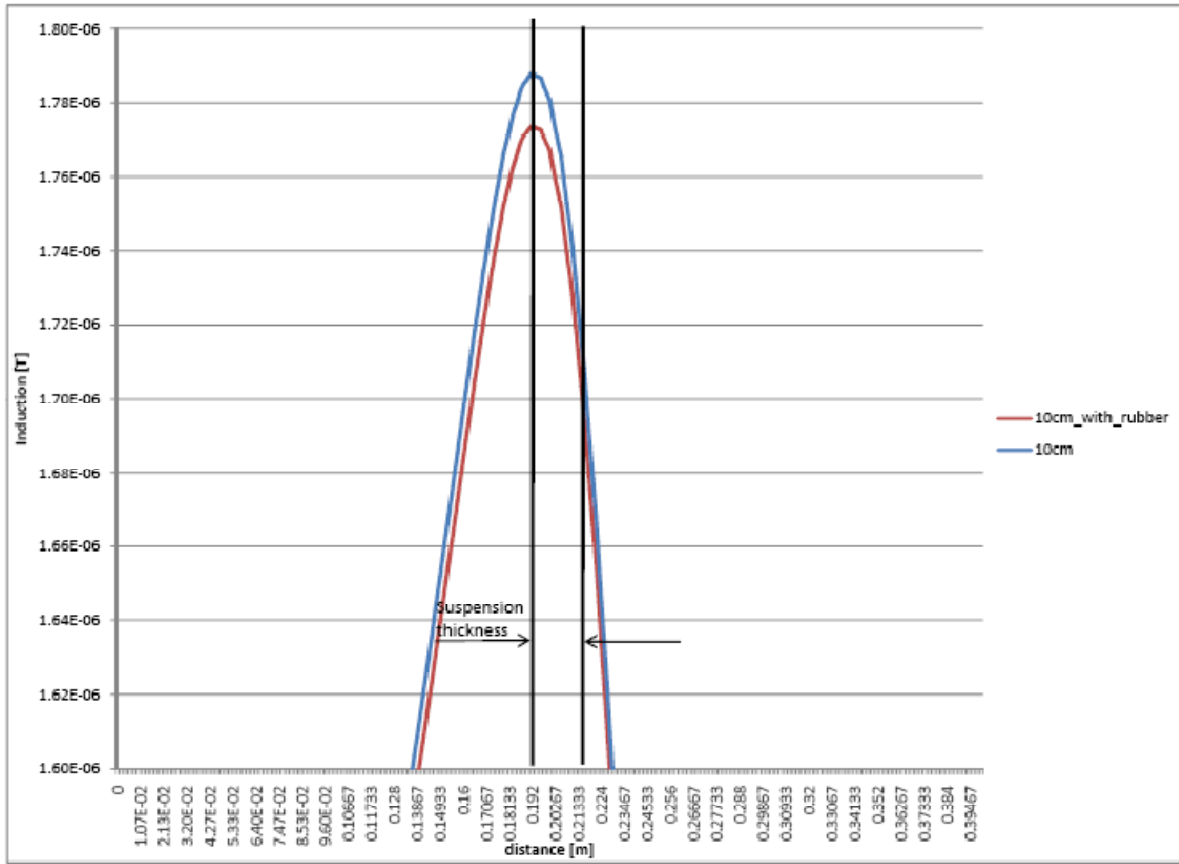


Figure 4.5 – Magnetic field values with and without the rubber insertions, zoom over the maximum values

Distance between the suspension parts and the trigger sender was modified along the x axis and y axis.

Figure 4.6 shows the values of the magnetic field (crosstalk) in the opposite part of the suspensions, along a defined path 'path' (see **Figure 3.23**). This path was defined where the wheel electronic would be situated and the values were read in a text file. The file was later imported in an excel table for the charts in the figures. As expected, the field intensity has the maximum value on the suspension direction and decreases with the distance to the left and right of the suspensions. As a matter of quality, the simulations show a correct result, but as a matter of quantity, an abstraction of the values can be made due to the explained geometry constraints. Δx is the distance from the minimum to the maximum position where the field was measured ($\Delta x = 40\text{cm}$) and it was increased in steps of 2cm. This also shows a decrease of the field strength with the distance (**Figure 4.7**).

The same simulations were made modifying the distance over the y value. Results are to be seen in charts from **Figure 4.8** and **Figure 4.9**. Again, the magnetic field intensity decreases with the distance.

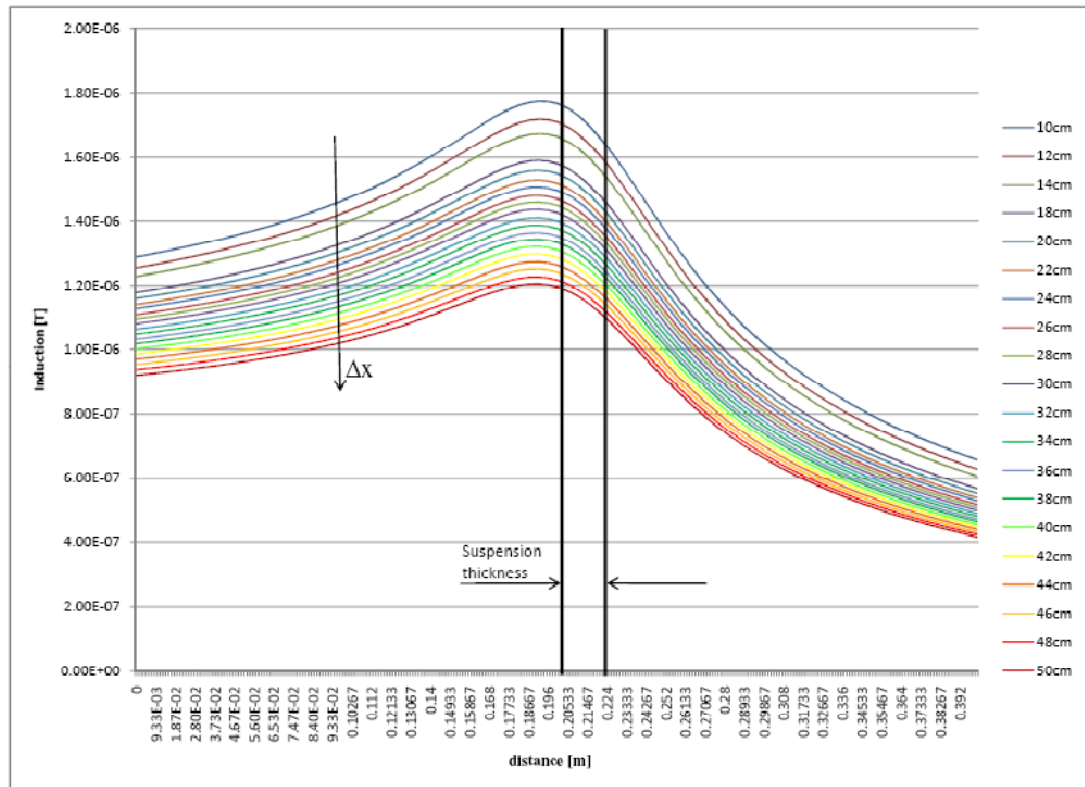


Figure 4.6 – Magnetic field values over a path in the opposite wheel

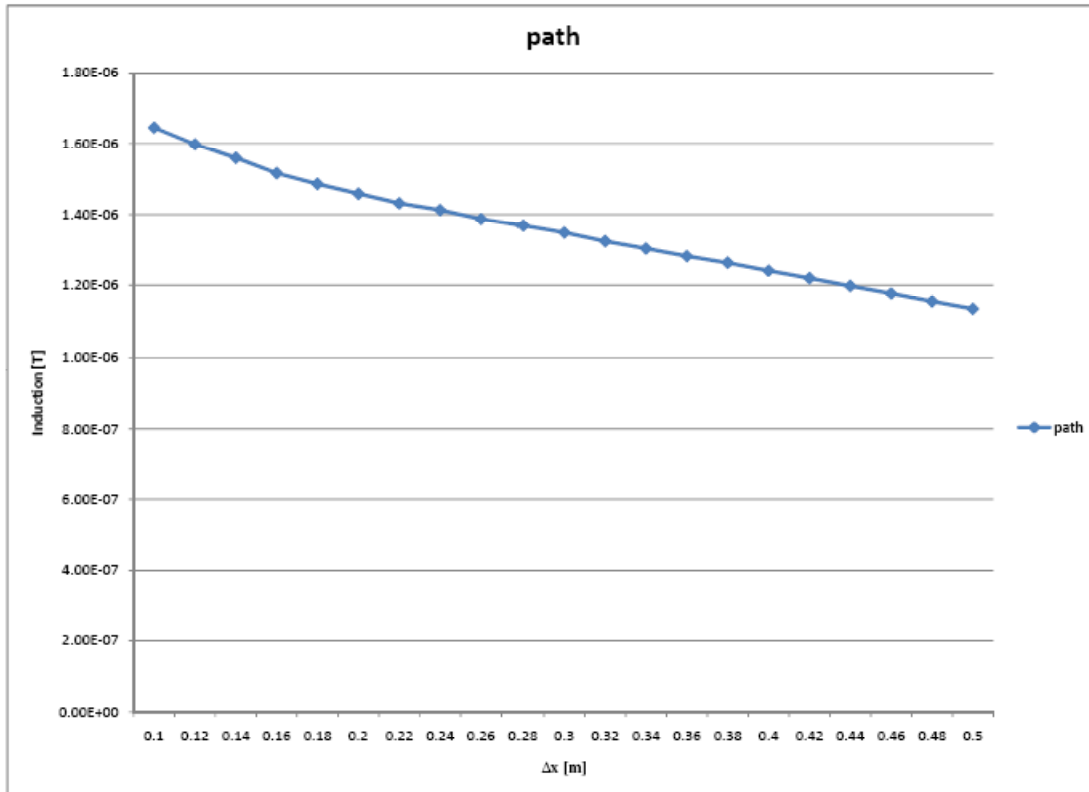


Figure 4.7 – Magnetic field values in one point over Δx distance

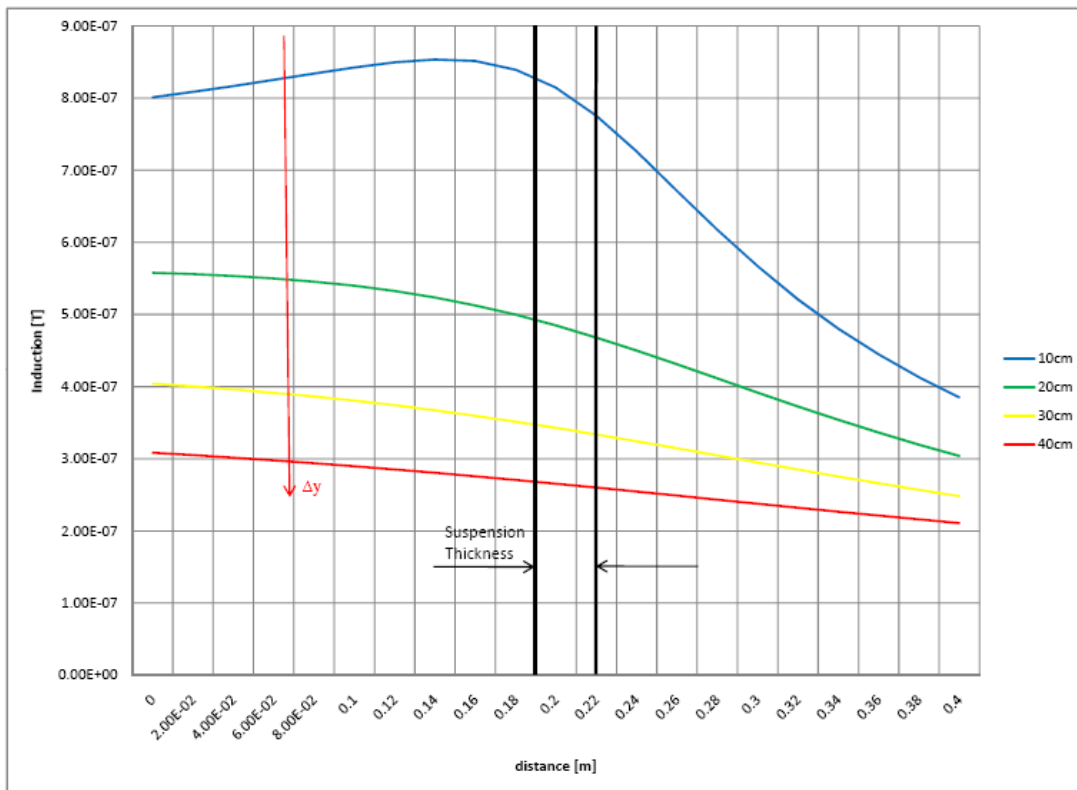


Figure 4.8 – Magnetic field values over a path in the opposite wheel

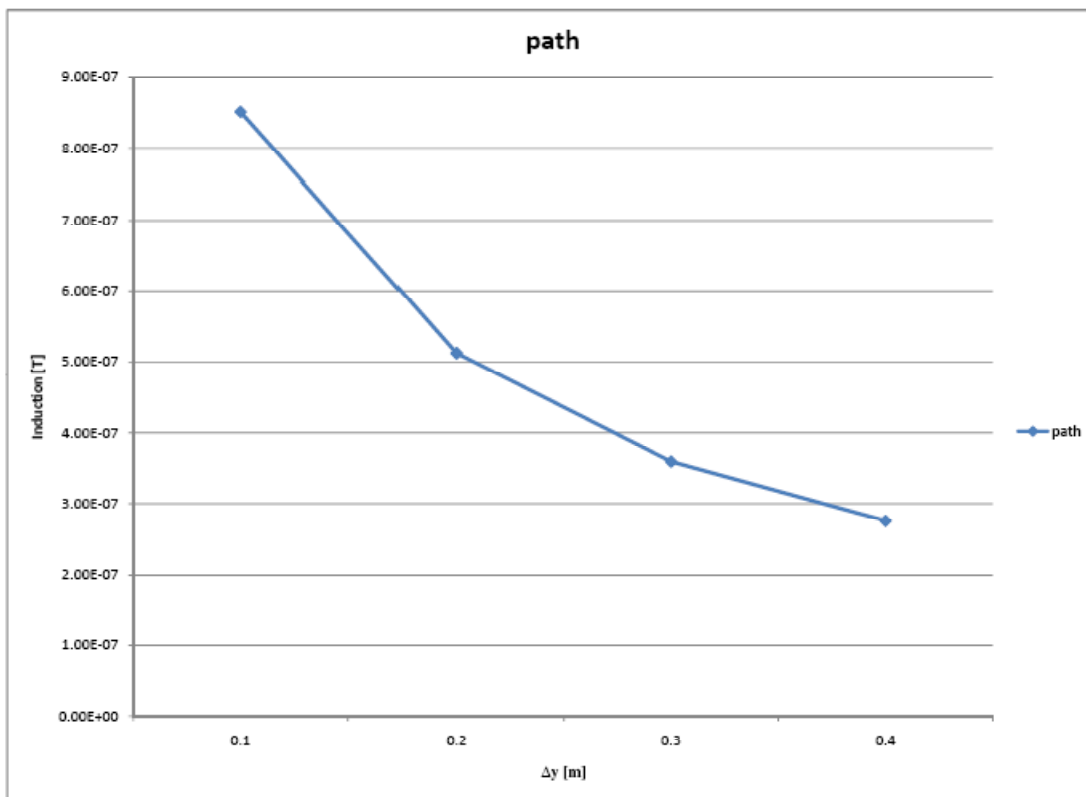


Figure 4.9 – Magnetic field values in one point over Δy distance



A chart was made out of the values over the plotted paths (**Figure 3.26**). Induced magnetic field over 'P1' path is plotted in **Figure 4.10** and this field determines the flow of eddy currents through the metal parts of the suspension and there is a crosstalking on the opposite wheel, over 'P2' path. These values are plotted in **Figure 4.11**.

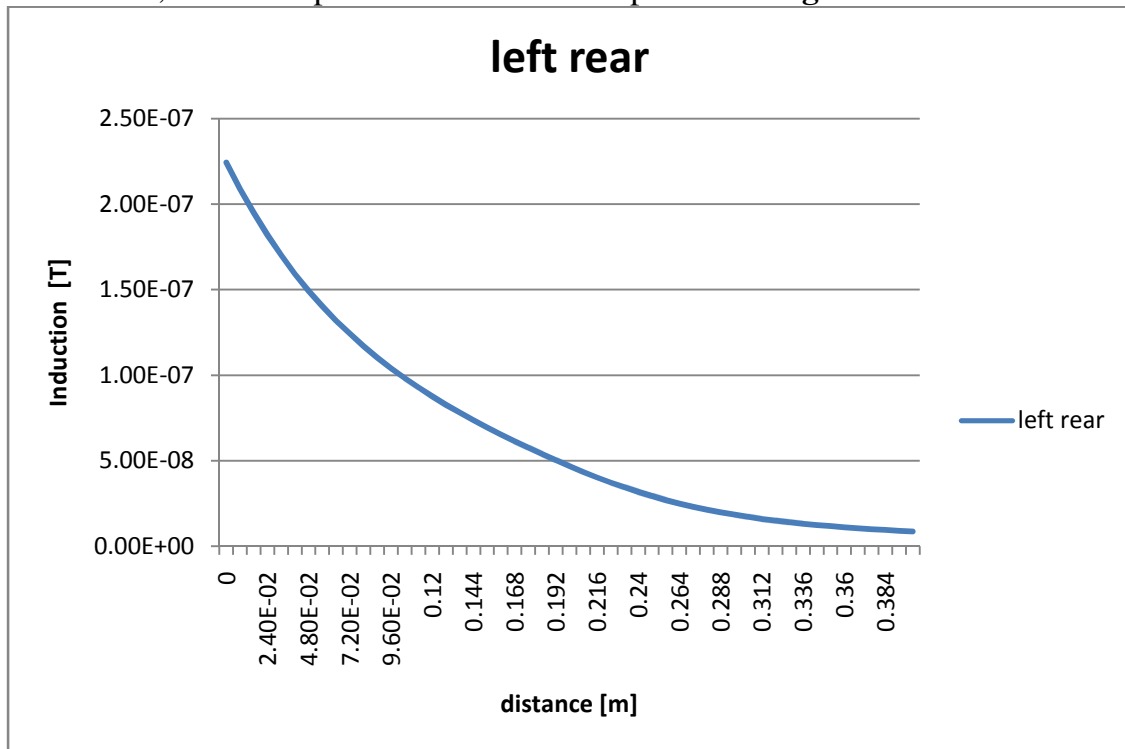


Figure 4.10 – Magnetic field on the left rear wheel

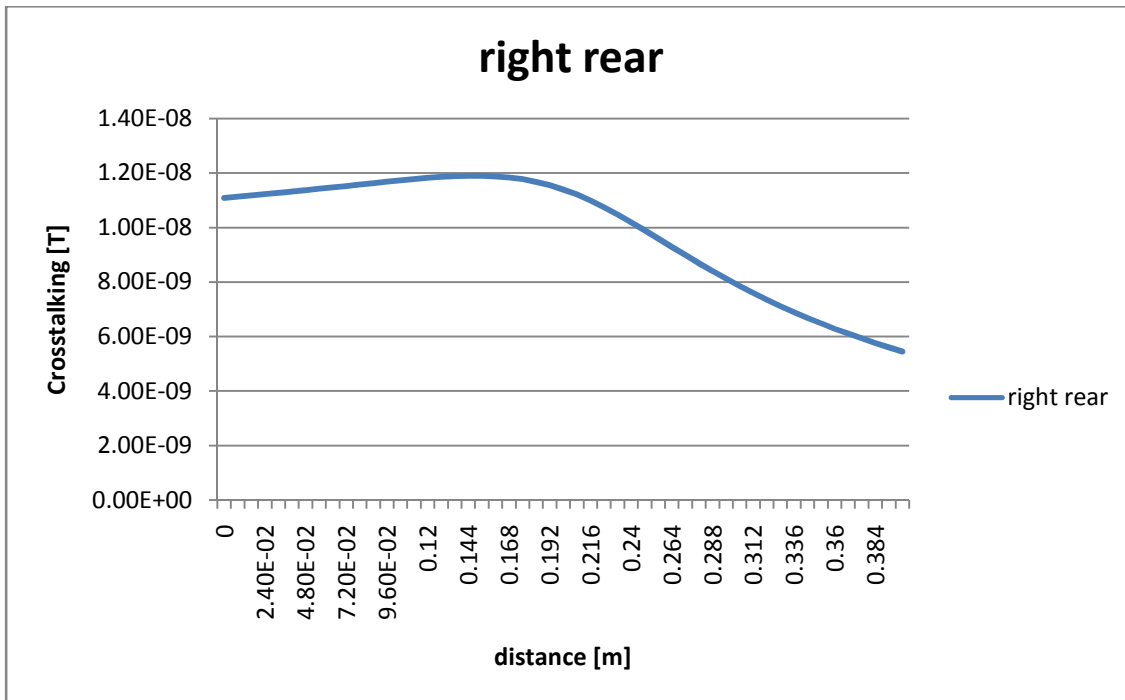


Figure 4.11 – Crosstalking on the right rear wheel



Comparing the results of the measurements on the wheels and the results of the simulations of the magnetic field in the wheels, it is possible to see that for some points, the results have closed values. Of course, there cannot be made a full comparison of these results, because the simulations retrieve values over a 2-D magnetic field, and the measurements are done in a 3-D space.

Conclusions:

- The most important conclusion is the one that the magnetic field changes by introducing metal parts. So the suspension parts play a main role in the crosstalking, the way they are build and isolated determines the proper functionality of the Tyre Safety System.
- The second conclusion is that the car geometry, even only the suspension parts, is too complex to be simulated tri-dimensional by ANSYS Classics with medium computer resources. ANSYS is a good software for simulating electromagnetic fields, but its capabilities are not strong enough to simulate this project.
- The triggering antenna two-dimensional simulation gave the proper results, which match the reality



References

1. ANSYS Version 11.0 Help Manual
2. www.ansys.com
3. www.wikipedia.org
4. www.beru.de

ANNEX 1 – General Terms

Term	Meaning
[B]	strain-displacement matrix
[C]	damping matrix
[Ct]	specific heat matrix
[D]	elasticity matrix
E	Young's modulus
{F}	force vector
[I]	identity matrix
{I}	current vector, associated with electrical potential DOFs
{J}	current vector, associated with magnetic potential DOFs
[K]	stiffness matrix
[K ^t]	conductivity matrix
[M]	mass matrix
[O]	null matrix
P, {P}	pressure (vector)
{Q}	heat flow vector
[S]	stress stiffness matrix
{T}	temperature vector
T	time, thickness
[T _R]	local to global conversion matrix
u, v, w, {u}	displacement, displacement vector
{V}	electric potential vector
δ U	virtual internal work
δ V	virtual external work
{W}	fluid flow vector
x, y, z	element coordinate
X, Y, Z	nodal coordinates (usually global Cartesian)
A	coefficient of thermal expansion
E	strain
N	Poisson's ratio
Σ	stress

ANNEX 2 – Source Code

1. Trigger Sender, quarter axisymmetric modeling.

```
/BATCH
/COM,ANSYS RELEASE 11.0  UP20070125   13:29:40  08/23/2007
/input,menust,tmp,",,,,,,,,,,,,,1
/GRA,POWER
/GST,ON
/PLO,INFO,3
/GRO,CURL,ON
/CPLANE,1
/REPLOT,RESIZE
WPSTYLE,,,,,,,,0
!
!*****
!Trigger Antenna - Quarter modeling, Axisymmetric
!*****
!
/GO
!*
/COM,
/COM,Preferences for GUI filtering have been set to display:
/COM, Magnetic-Nodal
!*
/UNITS,SI
!
/FILNAME,antenna,0
/title,Trigger Antenna Quarter modeling, Axisymmetric
/PREP7
EMUNIT,MKS
!
!*****
!Parameters
!*****
!
*SET,l,40e-3
*SET,r,2.85e-3
*SET,n,190
*SET,d_wire,0.17e-3
*SET,l_wire,n*d_wire
*SET,r1,1.5
*SET,r2,1.55
*SET,copper,1.72e-8
*SET,ferrite,5
*SET,ip,0.42
!*
!
!*****
!Element Types
!*****
!!!!!!!!!!!!!! Element for Air and Ferrite !!!!!!!!!!!!!!!
!
ET,1,PLANE53
!*
KEYOPT,1,1,0  ! DOF Az  for Air and Ferrite
KEYOPT,1,2,0
KEYOPT,1,3,1  ! axialsymmetric
KEYOPT,1,4,0
KEYOPT,1,5,0
KEYOPT,1,7,0
!*
!!!!!!!!!!!!!! Element for Coil !!!!!!!!!!!!!!!1
!
ET,2,PLANE53
!*
KEYOPT,2,1,1  ! DOF Az and Volt  for Coil
KEYOPT,2,2,0
KEYOPT,2,3,1  ! axialsymmetric
KEYOPT,2,4,0
KEYOPT,2,5,0
```

```

KEYOPT,2,7,0
!*
!!!!!!!!!!!!!!!!!!!!!!!!!!!! Element for Far-Field!!!!!!!!!!!!!!!!!!!!!!
!
ET,3,INFIN110
!*
KEYOPT,3,1,0 ! DOF Az for Far-Field
KEYOPT,3,2,1
KEYOPT,3,3,1 ! axialsymmetric
KEYOPT,3,6,0
!*
!
!*****
!Material Properties
!*****
MPTEMP,,,,,,,,
MPTEMP,1,0
MPDATA,MURX,1,,1
!*
MPTEMP,,,,,,,,
MPTEMP,1,0
MPDATA,MURX,2,,1
MPDATA,RSVX,2,,copper
!*
MPTEMP,,,,,,,,
MPTEMP,1,0
MPDATA,RSVX,3,,ferrite
!*
TB,BH,3,1,16,
TBTEMP,0
TBPT,,15,0.2
TBPT,,19,0.25
TBPT,,25,0.285
TBPT,,29,0.3
TBPT,,48,0.35
TBPT,,75,0.39
TBPT,,90,0.4
TBPT,,100,0.405
TBPT,,125,0.415
TBPT,,150,0.423
TBPT,,175,0.425
TBPT,,200,0.428
TBPT,,225,0.43
TBPT,,250,0.431
TBPT,,500,0.435
TBPT,,1000,0.44
!*
TBPLOT,BH,3
/GRID,1
/AXLAB,X,Magnetic Field Intensity [A/m]
/AXLAB,Y,Magnetic Flux Density[Tesla]
/PLOPTS,INFO,0
/PLOPTS,LEG1,1
/PLOPTS,LEG2,1
/PLOPTS,LEG3,1
/PLOPTS,FRAME,1
/PLOPTS,TITLE,1
/PLOPTS,MINM,1
/PLOPTS,FILE,0
/PLOPTS,LOGO,1
/PLOPTS,WINS,1
/PLOPTS,WP,0
/PLOPTS,DATE,1
/TRIAD,ORIG
/REPLOT
!*
/PNUM,KP,0
/PNUM,LINE,0
/PNUM,AREA,0
/PNUM,VOLU,0
/PNUM,NODE,0
/PNUM,TABN,0

```

```

/PNUM,SVAL,0
/NUMBER,1
!*
/PNUM,ELEM,0
/REPLOT
!*
/XRANGE,0,1100
/YRANGE,0,0.5
!rot
/COLOR,GRBAK,BLAC
/COLOR,GRID,LGRA
/COLOR,AXLAB,WHIT
/COLOR,CURVE,RED,1
/COLOR,CURVE,BMAG,2
/COLOR,CURVE,RED,3
/COLOR,CURVE,CBLU,4
/COLOR,CURVE,MRED,5
/COLOR,CURVE,GREE,6
/REPLOT
/GTHK,AXIS,1
/REPLOT
/XRANGE,0,100
/REPLOT
/PNUM,KP,0
/PNUM,LINE,0
/PNUM,AREA,0
/PNUM,VOLU,0
/PNUM,NODE,0
/PNUM,TABN,0
/PNUM,SVAL,0
/NUMBER,0
!*
/PNUM,ELEM,0
/REPLOT
!*
!
!*****
!Building Geometrie
!*****
!
/PNUM,KP,1
/PNUM,LINE,1
k, ,0,0,0
K, ,r,,,
K, ,r,l/2,,
K, ,0,l/2,,
FLST,3,1,3,ORDE,1
FITEM,3,2
KGEN,2,P51X, , ,d_wire, , , ,0
FLST,3,1,3,ORDE,1
FITEM,3,3
KGEN,2,P51X, , ,d_wire, , , ,0
K, ,r+d_wire,l_wire/2,,
FLST,3,1,3,ORDE,1
FITEM,3,7
KGEN,2,P51X, , , -d_wire, , , ,0
FLST,3,1,3,ORDE,1
FITEM,3,8
KGEN,2,P51X, , , -r, , , ,0
FLST,3,3,3,ORDE,2
FITEM,3,5
FITEM,3,-7
KGEN,2,P51X, , , r, , , ,0
FLST,3,4,3,ORDE,4
FITEM,3,3
FITEM,3,-4
FITEM,3,6
FITEM,3,11
KGEN,2,P51X, , , ,(l-l_wire)/2, , , ,0
LSTR, 1, 2
LSTR, 9, 8
LSTR, 4, 3

```



```

LSTR, 14, 13
LSTR, 2, 5
LSTR, 8, 7
LSTR, 3, 6
LSTR, 13, 15
LSTR, 5, 10
LSTR, 7, 12
LSTR, 6, 11
LSTR, 15, 16
LSTR,1,9
LSTR,2,8
LSTR,5,7
LSTR,10,12
LSTR,9,4
LSTR,8,3
LSTR,7,6
LSTR,12,11
LSTR,4,14
LSTR,3,13
LSTR,6,15
LSTR,11,16
K, ,r1,,,
K, ,,r1,,
FLST,2,2,8
LARC,17,18,1,r1,
K, ,r2,,,
K, ,,r2,,
FLST,2,2,8
LARC,19,20,1,r2,
LSTR,18,20
LSTR,17,19
LSTR,14,18
LSTR,10,17
LDIV,25, , ,3,0
LDIV,26, , ,3,0
LSTR, 16, 22
LDIV,29, , ,3,0
LDIV,35, , ,3,0
LDIV,30, , ,3,0
LDIV,29, , ,2,0
LDIV,35, , ,2,0
LDIV,30, , ,2,0
LSTR,31,32
LSTR,32,33
LSTR,25,27
LSTR,27,29
LSTR,26,28
LSTR,28,30
FLST,2,2,4,ORDE,2
FITEM,2,31
FITEM,2,25
LCOMB,P51X, ,0
FLST,2,2,4,ORDE,2
FITEM,2,33
FITEM,2,26
LCOMB,P51X, ,0
LSTR,22,24
! *****
! Creating areas & meshing
! *****
!
!!!!!!!!!!!!!!!!!!!!!!Antenna areas!!!!!!!!!!!!!!!!!!!!!!
!
FLST,2,4,4
FITEM,2,1
FITEM,2,2
FITEM,2,13
FITEM,2,14
AL,P51X
!*
FLST,2,4,4
FITEM,2,2

```

```

FITEM,2,3
FITEM,2,17
FITEM,2,18
AL,P51X
!*
FLST,2,4,4
FITEM,2,3
FITEM,2,4
FITEM,2,21
FITEM,2,22
AL,P51X
!*
FLST,2,4,4
FITEM,2,5
FITEM,2,6
FITEM,2,14
FITEM,2,15
AL,P51X
!*
FLST,2,4,4
FITEM,2,6
FITEM,2,7
FITEM,2,18
FITEM,2,19
AL,P51X
!*
FLST,2,4,4
FITEM,2,7
FITEM,2,8
FITEM,2,22
FITEM,2,23
AL,P51X
!*
FLST,2,4,4
FITEM,2,9
FITEM,2,10
FITEM,2,15
FITEM,2,16
AL,P51X
!*
FLST,2,4,4
FITEM,2,10
FITEM,2,11
FITEM,2,19
FITEM,2,20
AL,P51X
!*
FLST,2,4,4
FITEM,2,11
FITEM,2,12
FITEM,2,23
FITEM,2,24
AL,P51X
!*
FLST,5,8,4,ORDE,8
FITEM,5,1
FITEM,5,2
FITEM,5,3
FITEM,5,4
FITEM,5,9
FITEM,5,10
FITEM,5,11
FITEM,5,12
CM,_Y,LINE
LSEL,,,P51X
CM,_Y1,LINE
CMSEL,_,_Y
!*
LESIZE,_Y1,,,20,1,,,,,1
!*
FLST,5,4,4,ORDE,4
FITEM,5,5

```

```

FITEM,5,6
FITEM,5,7
FITEM,5,8
CM,_Y,LINE
LSEL,,,P51X
CM,_Y1,LINE
CMSEL,_,_Y
!*
LESIZE,_Y1,,,2,1,,,1
!*
FLST,5,4,4,ORDE,4
FITEM,5,13
FITEM,5,14
FITEM,5,15
FITEM,5,16
CM,_Y,LINE
LSEL,,,P51X
CM,_Y1,LINE
CMSEL,_,_Y
!*
LESIZE,_Y1,,,100,1,,,1
!*
FLST,5,8,4,ORDE,8
FITEM,5,17
FITEM,5,18
FITEM,5,19
FITEM,5,20
FITEM,5,21
FITEM,5,22
FITEM,5,23
FITEM,5,24
CM,_Y,LINE
LSEL,,,P51X
CM,_Y1,LINE
CMSEL,_,_Y
!*
LESIZE,_Y1,,,30,1,,,1
FLST,5,2,5,ORDE,2
FITEM,5,1
FITEM,5,2
ASEL,S,,,P51X
aatt,3
type,1
MSHAPE,0,2D
MSHKEY,0
amesh,all
FLST,5,1,5,ORDE,1
FITEM,5,4
ASEL,S,,,P51X
aplo
aatt,2
type,2
MSHAPE,0,2D
MSHKEY,0
amesh,all
FLST,5,6,5,ORDE,6
FITEM,5,3
FITEM,5,5
FITEM,5,6
FITEM,5,7
FITEM,5,8
FITEM,5,9
ASEL,S,,,P51X
aatt,1
aplo
type,1
MSHAPE,0,2D
MSHKEY,0
amesh,all
!
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!Air areas!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!1!!!!
!

```

```

FLST,2,6,4
FITEM,2,29
FITEM,2,45
FITEM,2,35
FITEM,2,4
FITEM,2,8
FITEM,2,12
AL,P51X
!*
FLST,2,6,4
FITEM,2,35
FITEM,2,30
FITEM,2,46
FITEM,2,24
FITEM,2,20
FITEM,2,16
AL,P51X
!*
FLST,5,3,4,ORDE,3
FITEM,5,29
FITEM,5,35
FITEM,5,30
CM,_Y,LINE
LSEL,,,P51X
CM,_Y1,LINE
CMSEL,_,_Y
!*
LESIZE,_Y1,,,60,5,,,,,1
FLST,5,1,4,ORDE,1
FITEM,5,45
CM,_Y,LINE
LSEL,,,P51X
CM,_Y1,LINE
CMSEL,_,_Y
!*
LESIZE,_Y1,,,20,,,,,1
FLST,5,1,4,ORDE,1
FITEM,5,46
CM,_Y,LINE
LSEL,,,P51X
CM,_Y1,LINE
CMSEL,_,_Y
!*
LESIZE,_Y1,,,50,,,,,1
FLST,5,2,5,ORDE,2
FITEM,5,10
FITEM,5,11
ASEL,S,,,P51X
aatt,1
type,1
MSHAPE,0,2D
MSHKEY,0
amesh,all
!
FLST,2,4,4
FITEM,2,45
FITEM,2,42
FITEM,2,43
FITEM,2,47
AL,P51X
!*
FLST,2,4,4
FITEM,2,43
FITEM,2,44
FITEM,2,46
FITEM,2,48
AL,P51X
!*
FLST,5,3,4,ORDE,3
FITEM,5,42
FITEM,5,43
FITEM,5,44

```

```

CM,_Y,LINE
LSEL,,,,P51X
CM,_Y1,LINE
CMSEL,,_Y
!*
LESIZE,_Y1,,,40,2,,,,1
!*
FLST,5,1,4,ORDE,1
FITEM,5,47
CM,_Y,LINE
LSEL,,,,P51X
CM,_Y1,LINE
CMSEL,,_Y
!*
LESIZE,_Y1,,,20,,,,1
FLST,5,1,4,ORDE,1
FITEM,5,48
CM,_Y,LINE
LSEL,,,,P51X
CM,_Y1,LINE
CMSEL,,_Y
!*
LESIZE,_Y1,,,50,,,,1
!
FLST,5,3,4,ORDE,3
FITEM,5,29
FITEM,5,35
FITEM,5,30
CM,_Y,LINE
LSEL,,,,P51X
CM,_Y1,LINE
CMSEL,,_Y
!*
LESIZE,_Y1,,,60,10,,,,1
FLST,5,3,4,ORDE,3
FITEM,5,29
FITEM,5,35
FITEM,5,30
CM,_Y,LINE
LSEL,,,,P51X
CM,_Y1,LINE
CMSEL,,_Y
!*
LESIZE,_Y1,,,60,15,,,,1
FLST,5,1,4,ORDE,1
FITEM,5,45
CM,_Y,LINE
LSEL,,,,P51X
CM,_Y1,LINE
CMSEL,,_Y
!*
LESIZE,_Y1,,,14,,,,1
FLST,5,1,4,ORDE,1
FITEM,5,46
CM,_Y,LINE
LSEL,,,,P51X
CM,_Y1,LINE
CMSEL,,_Y
!*
FLST,5,1,4,ORDE,1
FITEM,5,46
CM,_Y,LINE
LSEL,,,,P51X
CM,_Y1,LINE
CMSEL,,_Y
!*
LESIZE,_Y1,,,30,,,,1
!
FLST,2,2,5,ORDE,2
FITEM,2,10
FITEM,2,-11
ACLEAR,P51X

```

```

FLST,5,2,5,ORDE,2
FITEM,5,10
FITEM,5,-11
ASEL,S,,P51X
aatt,1
amesh,all
!
alls
FLST,5,2,5,ORDE,2
FITEM,5,12
FITEM,5,13
ASEL,S,,P51X
aatt,1
type,1
MSHAPE,0,2D
MSHKEY,0
amesh,all
FLST,2,4,4
FITEM,2,47
FITEM,2,49
FITEM,2,36
FITEM,2,38
AL,P51X
!*
FLST,2,4,4
FITEM,2,38
FITEM,2,40
FITEM,2,48
FITEM,2,50
AL,P51X
!*
FLST,2,2,5,ORDE,2
FITEM,2,12
FITEM,2,-13
ACLEAR,P51X
!
!
FLST,5,3,4,ORDE,2
FITEM,5,42
FITEM,5,-44
CM,_Y,LINE
LSEL,,,,P51X
CM,_Y1,LINE
CMSEL,,_Y
!*
LESIZE,_Y1,,,24,,,,,1
!*
lplo
FLST,5,1,4,ORDE,1
FITEM,5,47
CM,_Y,LINE
LSEL,,,,P51X
CM,_Y1,LINE
CMSEL,,_Y
!*
LESIZE,_Y1,,,16,,,,,1
!*
FLST,5,1,4,ORDE,1
FITEM,5,48
CM,_Y,LINE
LSEL,,,,P51X
CM,_Y1,LINE
CMSEL,,_Y
!*
LESIZE,_Y1,,,14,,,,,1
!*
FLST,5,1,4,ORDE,1
FITEM,5,48
CM,_Y,LINE
LSEL,,,,P51X
CM,_Y1,LINE
CMSEL,,_Y

```

```

!*
LESIZE,_Y1,,,34,,,,,1
!*
FLST,5,2,5,ORDE,2
FITEM,5,12
FITEM,5,-13
ASEL,S,,,P51X
aatt,1
FLST,5,2,5,ORDE,2
FITEM,5,12
FITEM,5,-13
CM,_Y,AREA
ASEL,,,,P51X
CM,_Y1,AREA
CHKMSH,'AREA'
CMSEL,S,_Y
!*
AMESH,_Y1
!*
CMDELE,_Y
CMDELE,_Y1
CMDELE,_Y2
!*
alls
FLST,5,5,4,ORDE,5
FITEM,5,32
FITEM,5,34
FITEM,5,36
FITEM,5,38
FITEM,5,49
CM,_Y,LINE
LSEL,,,,P51X
CM,_Y1,LINE
CMSEL,,_Y
!*
LESIZE,_Y1,,,14,,,,,1
!*
FLST,5,3,4,ORDE,3
FITEM,5,37
FITEM,5,39
FITEM,5,41
CM,_Y,LINE
LSEL,,,,P51X
CM,_Y1,LINE
CMSEL,,_Y
!*
LESIZE,_Y1,,,8,,,,,1
!*
FLST,5,1,4,ORDE,1
FITEM,5,40
CM,_Y,LINE
LSEL,,,,P51X
CM,_Y1,LINE
CMSEL,,_Y
!*
LESIZE,_Y1,,,14,,,,,1
!*
FLST,5,3,4,ORDE,3
FITEM,5,25
FITEM,5,-26
FITEM,5,50
CM,_Y,LINE
LSEL,,,,P51X
CM,_Y1,LINE
CMSEL,,_Y
!*
LESIZE,_Y1,,,17,,,,,1
!*
FLST,5,2,5,ORDE,2
FITEM,5,14
FITEM,5,-15
ASEL,S,,,P51X

```

```

aatt,1
!
FLST,5,2,5,ORDE,2
FITEM,5,14
FITEM,5,-15
CM,_Y,AREA
ASEL,,,P51X
CM,_Y1,AREA
CHKMSH,'AREA'
CMSEL,S,_Y
!*
AMESH,_Y1
!*
CMDELE,_Y
CMDELE,_Y1
CMDELE,_Y2
!*
ACLEAR, 15
!
FLST,5,3,4,ORDE,3
FITEM,5,25
FITEM,5,-26
FITEM,5,50
CM,_Y,LINE
LSEL,,,P51X
CM,_Y1,LINE
CMSEL,,_Y
!*
LESIZE,_Y1,,,34,,,,,1
!*
FLST,5,2,4,ORDE,2
FITEM,5,40
FITEM,5,-41
CM,_Y,LINE
LSEL,,,P51X
CM,_Y1,LINE
CMSEL,,_Y
!*
LESIZE,_Y1,,,14,,,,,1
!*
ASEL,S,,, 15
aatt,1
amesh,all
!
alls
FLST,2,4,4
FITEM,2,32
FITEM,2,37
FITEM,2,49
FITEM,2,39
AL,P51X
FLST,2,4,4
FITEM,2,39
FITEM,2,50
FITEM,2,25
FITEM,2,41
AL,P51X
FLST,2,4,4
FITEM,2,34
FITEM,2,32
FITEM,2,27
FITEM,2,31
AL,P51X
FLST,2,4,4
FITEM,2,25
FITEM,2,26
FITEM,2,31
FITEM,2,28
AL,P51X
FLST,5,2,5,ORDE,2
FITEM,5,16
FITEM,5,-17

```



```

ASEL,S,,P51X
!
type,1
aatt,1
amesh,all
!
alls
FLST,5,1,4,ORDE,1
FITEM,5,26
CM,_Y,LINE
LSEL,,,,P51X
CM,_Y1,LINE
CMSEL,_,_Y
!*
LESIZE,_Y1,,,34,,,,,1
!*
FLST,5,3,4,ORDE,3
FITEM,5,27
FITEM,5,-28
FITEM,5,31
CM,_Y,LINE
LSEL,,,,P51X
CM,_Y1,LINE
CMSEL,_,_Y
!*
LESIZE,_Y1,1,,,,,,1
!*
!
! !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!Far Field !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
!
FLST,5,2,5,ORDE,2
FITEM,5,18
FITEM,5,-19
ASEL,S,,P51X
esla
eplo
type,3
aatt,1
amesh,all
!
alls
NUMCMP,ALL
numm,node,1e-10
numm,kp,1e-10
!
/reset
eplo
!
!*****
!
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!Infinte Flag on Nodes!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
!
CSYS,1
NSEL,S,LOC,X,r2
SF,ALL,INF
!
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!Coupling DOF's in Volt !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
!
esel,s,mat,,2
eplo
nsle
nplo
!
cp,1,volt,all
!
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!Flux Parallel on Nodes!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
!
alls
CSYS,0
NSEL,S,LOC,X,0
D,ALL,AZ,0
alls

```

```

!
!!!!!!!!!!!!!!!!!!!!!!!!!!!!Total Current n*ip on Coil Node !!!!!!!!!!!!!
!
FLST,2,1,1,ORDE,1
FITEM,2,8360
!*
/GO
F,P51X,AMPS,n*ip
!
*****
!
alls
!
/REPLOT
!
*****
! Modell_1.png
*****
!
/ZOOM,1,RECT,-0.607660,-0.837162,-0.529600,-0.934122
/ZOOM,1,RECT,0.125632,0.156081,0.546683,-0.534459
!
*****
! Modell_1_zoom.png
*****
eplo
/PNUM,mat,1
/REPLOT
/EDGE,1,1
/REPLOT
/PNUM,KP,0
/PNUM,LINE,0
/PNUM,AREA,0
/PNUM,VOLU,0
/PNUM,NODE,0
/PNUM,TABN,0
/PNUM,SVAL,0
/NUMBER,1
!*
/PNUM,MAT,1
/REPLOT
!*
!
*****
! Modell_1a_zoom.png
*****
!
/ZOOM, 1, 0.63605E-02, 0.19990E-01, 0.0000 , 0.41329E-01
/ZOOM, 1, 0.77500 , 0.77500 , 0.0000 , 0.85250
!
fini
!
/SOLU
ALLSEL,ALL
!*
ANTYPE,3
HARFRQ,125000,0,
NSUBST, ,
KBC,0
!*
/STATUS,SOLU
SOLVE
save
!
FINISH
!
/POST1
!
SET,LIST
SET,FIRST
!
/PLOPTS,INFO,1

```

```

/PLOPTS,LEG1,1
/PLOPTS,LEG2,0
/PLOPTS,LEG3,1
/PLOPTS,FRAME,1
/PLOPTS,TITLE,1
/PLOPTS,MINM,1
/PLOPTS,FILE,0
/PLOPTS,LOGO,0
/PLOPTS,WINS,0
/PLOPTS,WP,0
/PLOPTS,DATE,1
/TRIAD,ORIG
!
PLF2D,60,0,10,1
!*
!*****
! fluss_2D_1.png
!*****
!
/ZOOM,1,RECT,-0.919900,-0.851351,-0.867860,-0.915203
/ZOOM,1,RECT,-0.569812,0.144257,0.087785,-0.870270
!*****
! fluss_2D_zoom.png
!*****
/ZOOM, 1, 0.12967E-01, 0.22006E-01, 0.0000 , 0.27217E-01
/ZOOM, 1, 0.77500 , 0.77500 , 0.0000 , 0.85250
esel,s,mat,,1
!*
/EFACET,1
!*
/SHOW,WIN32C
/DEVICE,VECTOR,0
/DEVICE,BBOX,1
/DEVICE,DITHER,1
/DEVICE,ANIM,BMP
! /UIS,DYNA,0
! /UIS,ZPIC,0
!*
! /DEV,FONT,LEGEND,MENU
/dev,font,1,Courier*New,400,0,-16,0,0,,,
/CONT,1,30,0.02, ,0.2
!*
/EDGE,1,0
!*
/CONT,1,38,5e-009, ,3e-008
PLNSOL, B,SUM, 0
!*****
! Bsum_Luft_1.png
!*****
/CONT,1,38,0.0005,0.005,
PLNSOL, B,SUM, 0
/ZOOM,1,RECT,-0.926996,-0.841892,-0.863129,-0.922297
/ZOOM,1,RECT,-0.498849,0.472973,0.480450,-0.780405
alls
esel,u,mat,,1
/noerase
PLNSOL, B,SUM, 0
!*****
! Bsum_Ferrite_Luft_1.png
!*****
/erase
alls
!*
/EFACET,1
esel,s,mat,,1
/CONT,1,30,0,0.5,
PLNSOL, H,SUM, 0
alls
esel,u,mat,,1
/noerase
PLNSOL, H,SUM, 0
!*****

```

```

! Hsum_Ferrite_1.png
!*****
/erase
alls
/CONT,1,29,0,2500,
PLNSOL, H,SUM, 0
!*****
! Hsum_Luft_1.png
!*****
/ZOOM, 1, 0.11959E-01, 0.23014E-01, 0.0000 , 0.34273E-01
/ZOOM, 1, 0.77500 , 0.77500 , 0.0000 , 0.85250
!
/CONT,1,30,0,0.005,
PLNSOL, H,SUM, 0
!*****
! Hsum_Luft_2.png
!*****
FLST,2,11,1
FITEM,2,1
FITEM,2,8103
FITEM,2,10926
FITEM,2,23027
FITEM,2,23078
FITEM,2,23089
FITEM,2,31858
FITEM,2,35321
FITEM,2,37085
FITEM,2,37010
FITEM,2,38560
!*
PATH,Bsum,11,30,20,
PPATH,P51X,1
PATH,STAT
!*
PDEF,Bsum,B,SUM,AVG
/PBC,PATH, ,0
PLPATH,BSUM
!*
/GRID,1
/PNUM,KP,0
/PNUM,LINE,0
/PNUM,AREA,0
/PNUM,VOLU,0
/PNUM,NODE,0
/PNUM,TABN,0
/PNUM,SVAL,0
/NUMBER,1
!*
/PNUM,ELEM,0
!*
! /DEV,FONT,LEGEND,MENU
/dev,font,1,Courier*New,400,0,-21,0,0,,,
!*
/PLOPTS,INFO,0
/PLOPTS,LEG1,1
/PLOPTS,LEG2,1
/PLOPTS,LEG3,1
/PLOPTS,FRAME,1
/PLOPTS,TITLE,1
/PLOPTS,MINM,1
/PLOPTS,FILE,0
/PLOPTS,LOGO,1
/PLOPTS,WINS,1
/PLOPTS,WP,0
/PLOPTS,DATE,1
/TRIAD,ORIG
!*
/reset
/GTHK,AXIS,1
/AXLAB,Y,Induction[Tesla]
/AXLAB,X,Path_X-Direction [m]
/YRANGE,0,0.15

```

```

/ XRANGE,0,0.01
PLPATH,BSUM
!
!*****
! Bsum_Pfad_X_1.png
!*****
/ XRANGE,1,1.001
/ YRANGE,10e-9,20e-9
PLPATH,BSUM
!*****
! Bsum_Pfad_X_2.png
!*****
FINISH
! /EXI ,nosave

```

2. Trigger sender, plane modelling, no symmetry

```

/BATCH
/COM,ANSYS RELEASE 11.0 UP20070125 08:57:49 07/09/2007
/input,menust,tmp,",,,,,,,,,1
/ GRA,POWER
/ GST,ON
/ PLO,INFO,3
/ GRO,CURL,ON
/ CPLANE,1
/ REPLOT,RESIZE
WPSTYLE,,,,,,,,0
!*
*****
!Trigger Antenna - All modeling, No Symmetry
!*****
/GO
!*
/COM,
/COM,Preferences for GUI filtering have been set to display:
/COM, Magnetic-Nodal
!*
/UNITS,SI
!
/FILENAME,no_sym,0
/title,Trigger Antenna ALL modeling
/ PREP7
EMUNIT,MKS
!
!*****
!Parameters
!*****
*SET,l,40e-3
*SET,r,2.85e-3
*SET,diam,2*r
*SET,n,180
*SET,d_wire,0.17e-3
*SET,l_wire,n*d_wire
*SET,r1,1.5
*SET,r2,1.55
*SET,copper,1.72e-8
*SET,ferrite,5
!*
!*****
!Element Types
!*****
ET,1,PLANE53
!*
KEYOPT,1,1,0
KEYOPT,1,2,0
KEYOPT,1,3,0
KEYOPT,1,4,0
KEYOPT,1,5,0
KEYOPT,1,7,0
!
ET,2,PLANE53
!*

```

```

KEYOPT,2,1,1
KEYOPT,2,2,0
KEYOPT,2,3,0
KEYOPT,2,4,0
KEYOPT,2,5,0
KEYOPT,2,7,0
!
ET,3,INFIN110
!*
KEYOPT,3,1,0
KEYOPT,3,2,1
KEYOPT,3,3,0
KEYOPT,3,6,0
!
!*
!*****
!Material Properties
!*****
MPTEMP,,,,,,,,
MPTEMP,1,0
MPDATA,MURX,1,,1
!
MPTEMP,,,,,,,,
MPTEMP,1,0
MPDATA,MURX,2,,1
MPDATA,RSVX,2,,copper
!
MPTEMP,,,,,,,,
MPTEMP,1,0
MPDATA,RSVX,3,,ferrite
!
TB,BH,3,1,16,
TBTEMP,0
TBPT,,15,0.2
TBPT,,19,0.25
TBPT,,25,0.285
TBPT,,29,0.3
TBPT,,48,0.35
TBPT,,75,0.39
TBPT,,90,0.4
TBPT,,100,0.405
TBPT,,125,0.415
TBPT,,150,0.423
TBPT,,175,0.425
TBPT,,200,0.428
TBPT,,225,0.43
TBPT,,250,0.431
TBPT,,500,0.435
TBPT,,1000,0.44
!
!*****
!Building Geometrie
!*****
!
K, ,r,l/2,,
K, ,-r,l/2,,
K, ,r,-l/2,,
K, ,r,-l/2,,
LSTR, 1, 2
LSTR, 2, 3
LSTR, 3, 4
LSTR, 4, 1
K, ,r+d_wire,l_wire/2,,
K, ,r+d_wire,-l_wire/2,,
K, ,-r-d_wire,-l_wire/2,,
K, ,-r-d_wire,l_wire/2,,
LPLT
KPLT
FLST,3,2,3,ORDE,2
FITEM,3,7
FITEM,3,-8
KGEN,2,P51X, , ,d_wire, , , ,0

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```

FLST,3,2,3,ORDE,2
FITEM,3,5
FITEM,3,-6
KGEN,2,P51X,,, -d_wire,,,,0
FLST,3,2,3,ORDE,2
FITEM,3,2
FITEM,3,-3
KGEN,2,P51X,,, -d_wire,,,,0
FLST,3,2,3,ORDE,2
FITEM,3,1
FITEM,3,4
KGEN,2,P51X,,, +d_wire,,,,0
LSTR, 13, 2
LSTR, 8, 10
LSTR, 11, 5
LSTR, 1, 15
LSTR, 13, 8
LSTR, 15, 5
LSTR, 7, 9
LSTR, 12, 6
LSTR, 4, 16
LSTR, 14, 3
LSTR, 7, 14
LSTR, 6, 16
LSTR, 6, 5
LSTR, 8, 7
LPLOT
LSTR, 9, 12
LSTR, 10, 11
K, ,r1,,,
K, ,-r1,,,
K, ,,r1,,
K, ,, -r1,,
K, ,,,,
FLST,2,2,8
FITEM,2,0,0,0
FITEM,2,1.5,0,0
CIRCLE,P51X,,, ,360,,
LPLOT
FLST,2,4,3,ORDE,2
FITEM,2,17
FITEM,2,-20
KDELE,P51X
LPLOT
LDIV,21, , ,3,0
LDIV,22, , ,3,0
LDIV,23, , ,3,0
LDIV,24, , ,3,0
K, ,, -1/2,,
K, ,,1/2,,
K, ,-r-d_wire,,,
K, ,r+d_wire,,,
LSTR, 30, 25
LSTR, 3, 27
LSTR, 14, 26
LSTR, 32, 24
LSTR, 13, 20
LSTR, 2, 19
LSTR, 31, 23
LSTR, 1, 18
LSTR, 15, 17
LSTR, 33, 22
LSTR, 16, 29
LSTR, 4, 28
LDIV,33, , ,5,0
LDIV,34, , ,5,0
LDIV,35, , ,5,0
LDIV,36, , ,5,0
LDIV,37, , ,5,0
LDIV,38, , ,5,0
LDIV,39, , ,5,0
LDIV,40, , ,5,0

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```

LDIV,41, , ,5,0
LDIV,42, , ,5,0
LDIV,43, , ,5,0
LDIV,44, , ,5,0
FLST,5,24,4,ORDE,24
FITEM,5,33
FITEM,5,34
FITEM,5,35
FITEM,5,36
FITEM,5,37
FITEM,5,38
FITEM,5,39
FITEM,5,40
FITEM,5,41
FITEM,5,42
FITEM,5,43
FITEM,5,44
FITEM,5,45
FITEM,5,49
FITEM,5,53
FITEM,5,57
FITEM,5,61
FITEM,5,65
FITEM,5,69
FITEM,5,73
FITEM,5,77
FITEM,5,81
FITEM,5,85
FITEM,5,89
LSEL,S, , ,P51X
LDIV,all, , ,2,0
LSTR, 82, 83
LSTR, 83, 84
LSTR, 84, 85
LSTR, 85, 86
LSTR, 86, 87
LSTR, 87, 88
LSTR, 88, 89
LSTR, 89, 90
LSTR, 90, 91
LSTR, 91, 92
LSTR, 92, 93
LSTR, 93, 82
LSTR, 94, 95
LSTR, 95, 96
LSTR, 96, 97
LSTR, 97, 98
LSTR, 98, 99
LSTR, 99, 100
LSTR, 100, 101
LSTR, 101, 102
LSTR, 102, 103
LSTR, 103, 104
LSTR, 104, 105
LSTR, 105, 94
LSTR, 36, 40
LSTR, 40, 44
LSTR, 44, 48
LSTR, 48, 52
LSTR, 52, 56
LSTR, 56, 60
LSTR, 60, 64
LSTR, 64, 68
LSTR, 68, 72
LSTR, 72, 76
LSTR, 76, 80
LSTR, 80, 36
FLST,2,2,4,ORDE,2
FITEM,2,93
FITEM,2,45
LCOMB,P51X, ,0
FLST,2,2,4,ORDE,2

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FITEM,2,94
FITEM,2,49
LCOMB,P51X, 0
FLST,2,2,4,ORDE,2
FITEM,2,95
FITEM,2,53
LCOMB,P51X, 0
FLST,2,2,4,ORDE,2
FITEM,2,96
FITEM,2,57
LCOMB,P51X, 0
FLST,2,2,4,ORDE,2
FITEM,2,97
FITEM,2,61
LCOMB,P51X, 0
FLST,2,2,4,ORDE,2
FITEM,2,98
FITEM,2,65
LCOMB,P51X, 0
FLST,2,2,4,ORDE,2
FITEM,2,99
FITEM,2,69
LCOMB,P51X, 0
FLST,2,2,4,ORDE,2
FITEM,2,100
FITEM,2,73
LCOMB,P51X, 0
FLST,2,2,4,ORDE,2
FITEM,2,101
FITEM,2,77
LCOMB,P51X, 0
FLST,2,2,4,ORDE,2
FITEM,2,102
FITEM,2,81
LCOMB,P51X, 0
FLST,2,2,4,ORDE,2
FITEM,2,103
FITEM,2,85
LCOMB,P51X, 0
FLST,2,2,4,ORDE,2
FITEM,2,104
FITEM,2,89
LCOMB,P51X, 0
FLST,2,2,4,ORDE,2
FITEM,2,105
FITEM,2,46
LCOMB,P51X, 0
FLST,2,2,4,ORDE,2
FITEM,2,106
FITEM,2,50
LCOMB,P51X, 0
FLST,2,2,4,ORDE,2
FITEM,2,107
FITEM,2,54
LCOMB,P51X, 0
FLST,2,2,4,ORDE,2
FITEM,2,108
FITEM,2,58
LCOMB,P51X, 0
FLST,2,2,4,ORDE,2
FITEM,2,109
FITEM,2,62
LCOMB,P51X, 0
FLST,2,2,4,ORDE,2
FITEM,2,110
FITEM,2,66
LCOMB,P51X, 0
FLST,2,2,4,ORDE,2
FITEM,2,111
FITEM,2,70
LCOMB,P51X, 0
FLST,2,2,4,ORDE,2

FITEM,2,112
FITEM,2,74
LCOMB,P51X, 0
FLST,2,2,4,ORDE,2
FITEM,2,113
FITEM,2,78
LCOMB,P51X, 0
FLST,2,2,4,ORDE,2
FITEM,2,114
FITEM,2,82
LCOMB,P51X, 0
FLST,2,2,4,ORDE,2
FITEM,2,115
FITEM,2,86
LCOMB,P51X, 0
FLST,2,2,4,ORDE,2
FITEM,2,116
FITEM,2,90
LCOMB,P51X, 0
FLST,2,2,4,ORDE,2
FITEM,2,47
FITEM,2,48
LCOMB,P51X, 0
FLST,2,2,4,ORDE,2
FITEM,2,51
FITEM,2,52
LCOMB,P51X, 0
FLST,2,2,4,ORDE,2
FITEM,2,55
FITEM,2,56
LCOMB,P51X, 0
FLST,2,2,4,ORDE,2
FITEM,2,59
FITEM,2,60
LCOMB,P51X, 0
FLST,2,2,4,ORDE,2
FITEM,2,63
FITEM,2,64
LCOMB,P51X, 0
FLST,2,2,4,ORDE,2
FITEM,2,67
FITEM,2,68
LCOMB,P51X, 0
FLST,2,2,4,ORDE,2
FITEM,2,71
FITEM,2,72
LCOMB,P51X, 0
FLST,2,2,4,ORDE,2
FITEM,2,75
FITEM,2,76
LCOMB,P51X, 0
FLST,2,2,4,ORDE,2
FITEM,2,79
FITEM,2,80
LCOMB,P51X, 0
FLST,2,2,4,ORDE,2
FITEM,2,83
FITEM,2,84
LCOMB,P51X, 0
FLST,2,2,4,ORDE,2
FITEM,2,87
FITEM,2,88
LCOMB,P51X, 0
FLST,2,2,4,ORDE,2
FITEM,2,91
FITEM,2,92
LCOMB,P51X, 0
FLST,2,1,4,ORDE,1
FITEM,2,3
FLST,3,1,4,ORDE,1
FITEM,3,33
LSBL,P51X,P51X, ,DELETE,KEEP

```

FLST,2,1,4,ORDE,1
FITEM,2,18
FLST,3,1,4,ORDE,1
FITEM,3,36
LSBL,P51X,P51X, ,DELETE,KEEP
FLST,2,1,4,ORDE,1
FITEM,2,17
FLST,3,1,4,ORDE,1
FITEM,3,42
LSBL,P51X,P51X, ,DELETE,KEEP
FLST,2,1,4,ORDE,1
FITEM,2,1
FLST,3,1,4,ORDE,1
FITEM,3,39
LSBL,P51X,P51X, ,DELETE,KEEP
FLST,2,1,4,ORDE,1
FITEM,2,2
FLST,3,1,4,ORDE,1
FITEM,3,19
LSBL,P51X,P51X, ,DELETE,KEEP
FLST,2,1,4,ORDE,1
FITEM,2,4
FLST,3,1,4,ORDE,1
FITEM,3,19
LSBL,P51X,P51X, ,DELETE,KEEP
FLST,2,1,4,ORDE,1
FITEM,2,1
FLST,3,1,4,ORDE,1
FITEM,3,20
LSBL,P51X,P51X, ,DELETE,KEEP
FLST,2,1,4,ORDE,1
FITEM,2,2
FLST,3,1,4,ORDE,1
FITEM,3,20
LSBL,P51X,P51X, ,DELETE,KEEP
FLST,2,2,8
FITEM,2,0,0,0
FITEM,2,r2,0,0
CIRCLE,P51X
LDIV,2, , ,3,0
LDIV,92, , ,3,0
LDIV,88, , ,3,0
LDIV,84, , ,3,0
LSTR,24,37
LSTR,20,49
LSTR,19,47
LSTR,23,35
LSTR,18,41
LSTR,17,39
LSTR,22,34
LSTR,29,43
LSTR,28,42
LSTR,25,38
LSTR,27,46
LSTR,26,45
/PNUM,KP,1
/PNUM,LINE,1

!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!Areas!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!

FLST,2,4,4
FITEM,2,47
FITEM,2,141
FITEM,2,51
FITEM,2,30
AL,P51X
FLST,2,4,4
FITEM,2,51
FITEM,2,142
FITEM,2,55

```

FITEM,2,29
AL,P51X
FLST,2,4,4
FITEM,2,55
FITEM,2,143
FITEM,2,59
FITEM,2,23
AL,P51X
FLST,2,4,4
FITEM,2,144
FITEM,2,63
FITEM,2,28
FITEM,2,59
AL,P51X
FLST,2,4,4
FITEM,2,145
FITEM,2,67
FITEM,2,27
FITEM,2,63
AL,P51X
FLST,2,4,4
FITEM,2,146
FITEM,2,71
FITEM,2,22
FITEM,2,67
AL,P51X
FLST,2,4,4
FITEM,2,147
FITEM,2,75
FITEM,2,26
FITEM,2,71
AL,P51X
FLST,2,4,4
FITEM,2,148
FITEM,2,79
FITEM,2,25
FITEM,2,75
AL,P51X
FLST,2,4,4
FITEM,2,149
FITEM,2,83
FITEM,2,21
FITEM,2,79
AL,P51X
FLST,2,4,4
FITEM,2,150
FITEM,2,87
FITEM,2,32
FITEM,2,83
AL,P51X
FLST,2,4,4
FITEM,2,151
FITEM,2,91
FITEM,2,31
FITEM,2,87
AL,P51X
FLST,2,4,4
FITEM,2,152
FITEM,2,47
FITEM,2,24
FITEM,2,91
AL,P51X
FLST,2,4,4
FITEM,2,50
FITEM,2,141
FITEM,2,46
FITEM,2,129
AL,P51X
FLST,2,4,4
FITEM,2,130
FITEM,2,54
FITEM,2,142

FITEM,2,50
AL,P51X
FLST,2,4,4
FITEM,2,131
FITEM,2,58
FITEM,2,143
FITEM,2,54
AL,P51X
FLST,2,4,4
FITEM,2,132
FITEM,2,62
FITEM,2,144
FITEM,2,58
AL,P51X
FLST,2,4,4
FITEM,2,133
FITEM,2,66
FITEM,2,145
FITEM,2,62
AL,P51X
FLST,2,4,4
FITEM,2,134
FITEM,2,70
FITEM,2,146
FITEM,2,66
AL,P51X
FLST,2,4,4
FITEM,2,135
FITEM,2,74
FITEM,2,147
FITEM,2,70
AL,P51X
FLST,2,4,4
FITEM,2,136
FITEM,2,78
FITEM,2,148
FITEM,2,74
AL,P51X
FLST,2,4,4
FITEM,2,137
FITEM,2,82
FITEM,2,149
FITEM,2,78
AL,P51X
FLST,2,4,4
FITEM,2,82
FITEM,2,86
FITEM,2,138
FITEM,2,150
AL,P51X
FLST,2,4,4
FITEM,2,139
FITEM,2,90
FITEM,2,151
FITEM,2,86
AL,P51X
FLST,2,4,4
FITEM,2,140
FITEM,2,46
FITEM,2,152
FITEM,2,90
AL,P51X
FLST,2,4,4
FITEM,2,117
FITEM,2,49
FITEM,2,129
FITEM,2,45
AL,P51X
FLST,2,4,4
FITEM,2,118
FITEM,2,53
FITEM,2,130

FITEM,2,49
AL,P51X
FLST,2,4,4
FITEM,2,119
FITEM,2,57
FITEM,2,131
FITEM,2,53
AL,P51X
FLST,2,4,4
FITEM,2,120
FITEM,2,61
FITEM,2,132
FITEM,2,57
AL,P51X
FLST,2,4,4
FITEM,2,121
FITEM,2,65
FITEM,2,133
FITEM,2,61
AL,P51X
FLST,2,4,4
FITEM,2,122
FITEM,2,69
FITEM,2,134
FITEM,2,65
AL,P51X
FLST,2,4,4
FITEM,2,123
FITEM,2,73
FITEM,2,135
FITEM,2,69
AL,P51X
FLST,2,4,4
FITEM,2,124
FITEM,2,77
FITEM,2,136
FITEM,2,73
AL,P51X
FLST,2,4,4
FITEM,2,125
FITEM,2,81
FITEM,2,137
FITEM,2,77
AL,P51X
FLST,2,4,4
FITEM,2,126
FITEM,2,85
FITEM,2,138
FITEM,2,81
AL,P51X
FLST,2,4,4
FITEM,2,85
FITEM,2,89
FITEM,2,127
FITEM,2,139
AL,P51X
FLST,2,4,4
FITEM,2,128
FITEM,2,45
FITEM,2,140
FITEM,2,89
AL,P51X
FLST,2,4,4
FITEM,2,33
FITEM,2,117
FITEM,2,34
FITEM,2,48
AL,P51X
FLST,2,4,4
FITEM,2,14
FITEM,2,35
FITEM,2,34

FITEM,2,118
AL,P51X
FLST,2,5,4
FITEM,2,119
FITEM,2,35
FITEM,2,36
FITEM,2,15
FITEM,2,3
AL,P51X
FLST,2,5,4
FITEM,2,56
FITEM,2,9
FITEM,2,36
FITEM,2,37
FITEM,2,120
AL,P51X
FLST,2,4,4
FITEM,2,38
FITEM,2,37
FITEM,2,121
FITEM,2,5
AL,P51X
FLST,2,4,4
FITEM,2,64
FITEM,2,39
FITEM,2,38
FITEM,2,122
AL,P51X
FLST,2,4,4
FITEM,2,39
FITEM,2,123
FITEM,2,40
FITEM,2,17
AL,P51X
FLST,2,4,4
FITEM,2,40
FITEM,2,124
FITEM,2,41
FITEM,2,8
AL,P51X
FLST,2,5,4
FITEM,2,125
FITEM,2,41
FITEM,2,42
FITEM,2,18
FITEM,2,10
AL,P51X
FLST,2,5,4
FITEM,2,42
FITEM,2,126
FITEM,2,43
FITEM,2,16
FITEM,2,60
AL,P51X
FLST,2,4,4
FITEM,2,13
FITEM,2,43
FITEM,2,44
FITEM,2,127
AL,P51X
FLST,2,4,4
FITEM,2,44
FITEM,2,33
FITEM,2,128
FITEM,2,52
AL,P51X
FLST,2,4,4
FITEM,2,68
FITEM,2,15
FITEM,2,11
FITEM,2,14
AL,P51X

FLST,2,4,4
FITEM,2,12
FITEM,2,16
FITEM,2,72
FITEM,2,13
AL,P51X
FLST,2,5,4
FITEM,2,19
FITEM,2,68
FITEM,2,72
FITEM,2,48
FITEM,2,52
AL,P51X
FLST,2,4,4
FITEM,2,4
FITEM,2,9
FITEM,2,5
FITEM,2,6
AL,P51X
FLST,2,4,4
FITEM,2,8
FITEM,2,1
FITEM,2,10
FITEM,2,7
AL,P51X
FLST,2,5,4
FITEM,2,64
FITEM,2,17
FITEM,2,1
FITEM,2,20
FITEM,2,4
AL,P51X
FLST,2,5,4
FITEM,2,6
FITEM,2,56
FITEM,2,3
FITEM,2,11
FITEM,2,76
AL,P51X
FLST,2,5,4
FITEM,2,7
FITEM,2,18
FITEM,2,60
FITEM,2,12
FITEM,2,80
AL,P51X
FLST,2,4,4
FITEM,2,20
FITEM,2,19
FITEM,2,76
FITEM,2,80
AL,P51X
FLST,2,4,4
FITEM,2,101
FITEM,2,100
FITEM,2,28
FITEM,2,102
AL,P51X
FLST,2,4,4
FITEM,2,102
FITEM,2,27
FITEM,2,99
FITEM,2,103
AL,P51X
FLST,2,4,4
FITEM,2,103
FITEM,2,84
FITEM,2,22
FITEM,2,104
AL,P51X
FLST,2,4,4
FITEM,2,104


```

FITEM,2,94
FITEM,2,26
FITEM,2,105
AL,P51X
FLST,2,4,4
FITEM,2,105
FITEM,2,25
FITEM,2,93
FITEM,2,106
AL,P51X
FLST,2,4,4
FITEM,2,106
FITEM,2,2
FITEM,2,21
FITEM,2,107
AL,P51X
FLST,2,4,4
FITEM,2,107
FITEM,2,96
FITEM,2,32
FITEM,2,108
AL,P51X
FLST,2,4,4
FITEM,2,108
FITEM,2,31
FITEM,2,95
FITEM,2,109
AL,P51X
FLST,2,4,4
FITEM,2,109
FITEM,2,24
FITEM,2,92
FITEM,2,110
AL,P51X
FLST,2,4,4
FITEM,2,110
FITEM,2,98
FITEM,2,30
FITEM,2,111
AL,P51X
FLST,2,4,4
FITEM,2,111
FITEM,2,97
FITEM,2,29
FITEM,2,112
AL,P51X
FLST,2,4,4
FITEM,2,112
FITEM,2,88
FITEM,2,23
FITEM,2,101
AL,P51X
!
!*****
!Meshing
!*****
!
!
/PNUM,AREA,1
!
!
!*****Antenna Meshing*****
!
FLST,5,2,4,ORDE,2
FITEM,5,76
FITEM,5,80
CM,_Y,LINE
LSEL,, ,P51X
CM,_Y1,LINE
CMSEL,,_Y
!*
LESIZE,_Y1,, ,40,1,, ,1

```

```
FLST,5,4,4,ORDE,4
FITEM,5,4
FITEM,5,1
FITEM,5,68
FITEM,5,72
CM,_Y,LINE
LSEL,,,,P51X
CM,_Y1,LINE
CMSEL,,_Y
!*
LESIZE,_Y1,,,20,,,,,1
```

```
FLST,5,4,4,ORDE,4
FITEM,5,15
FITEM,5,16
FITEM,5,10
FITEM,5,9
CM,_Y,LINE
LSEL,,,,P51X
CM,_Y1,LINE
CMSEL,,_Y
!*
LESIZE,_Y1,,,20,,,,,1
```

```
FLST,5,8,4,ORDE,8
FITEM,5,5
FITEM,5,6
FITEM,5,8
FITEM,5,7
FITEM,5,11
FITEM,5,14
FITEM,5,12
FITEM,5,13
CM,_Y,LINE
LSEL,,,,P51X
CM,_Y1,LINE
CMSEL,,_Y
!*
LESIZE,_Y1,,,2,,,,,1
```

```
FLST,5,2,4,ORDE,2
FITEM,5,20
FITEM,5,19
CM,_Y,LINE
LSEL,,,,P51X
CM,_Y1,LINE
CMSEL,,_Y
!*
LESIZE,_Y1,,,12,,,,,1
```

```
FLST,5,4,4,ORDE,4
FITEM,5,48
FITEM,5,64
FITEM,5,17
FITEM,5,52
CM,_Y,LINE
LSEL,,,,P51X
CM,_Y1,LINE
CMSEL,,_Y
!*
LESIZE,_Y1,,,6,,,,,1
```

```
FLST,5,4,4,ORDE,4
FITEM,5,3
FITEM,5,56
FITEM,5,60
FITEM,5,18
CM,_Y,LINE
LSEL,,,,P51X
CM,_Y1,LINE
CMSEL,,_Y
```

```

!*
LESIZE,_Y1, , ,20, , , ,1

FLST,5,2,5,ORDE,2
FITEM,5,55
FITEM,5,56
ASEL,S, , ,P51X
aatt,2
type,2
MSHAPE,0,2D
MSHKEY,0
amesh,all

FLST,5,3,5,ORDE,3
FITEM,5,51
FITEM,5,54
FITEM,5,57
ASEL,S, , ,P51X
aatt,3
type,1
MSHAPE,0,2D
MSHKEY,0
amesh,all
!
!*****Air Meshing*****
!
FLST,5,4,5,ORDE,4
FITEM,5,49
FITEM,5,50
FITEM,5,52
FITEM,5,53
ASEL,S, , ,P51X
aatt,1
type,1
MSHAPE,0,2D
MSHKEY,0
amesh,all

FLST,5,12,4,ORDE,12
FITEM,5,33
FITEM,5,34
FITEM,5,35
FITEM,5,36
FITEM,5,37
FITEM,5,38
FITEM,5,39
FITEM,5,40
FITEM,5,41
FITEM,5,42
FITEM,5,43
FITEM,5,44
CM,_Y,LINE
LSEL, , , ,P51X
CM,_Y1,LINE
CMSEL,_,_Y
!*
LESIZE,_Y1, , ,40,3, , , ,1

FLST,5,12,4,ORDE,12
FITEM,5,117
FITEM,5,118
FITEM,5,119
FITEM,5,120
FITEM,5,121
FITEM,5,122
FITEM,5,123
FITEM,5,124
FITEM,5,125
FITEM,5,126
FITEM,5,127
FITEM,5,128
CM,_Y,LINE

```

```

LSEL, , , , P51X
CM, _Y1, LINE
CMSEL, _Y
!*
LESIZE, _Y1, , , 20, , , , 1

FLST, 5, 12, 5, ORDE, 12
FITEM, 5, 37
FITEM, 5, 38
FITEM, 5, 39
FITEM, 5, 40
FITEM, 5, 41
FITEM, 5, 42
FITEM, 5, 43
FITEM, 5, 44
FITEM, 5, 45
FITEM, 5, 46
FITEM, 5, 47
FITEM, 5, 48
ASEL, S, , , P51X
aatt, 1
type, 1
MSHAPE, 0, 2D
MSHKEY, 0
amesh, all

FLST, 5, 12, 4, ORDE, 12
FITEM, 5, 45
FITEM, 5, 49
FITEM, 5, 53
FITEM, 5, 57
FITEM, 5, 61
FITEM, 5, 65
FITEM, 5, 69
FITEM, 5, 73
FITEM, 5, 77
FITEM, 5, 81
FITEM, 5, 85
FITEM, 5, 89
CM, _Y, LINE
LSEL, , , , P51X
CM, _Y1, LINE
CMSEL, _Y
!*
LESIZE, _Y1, , , 40, 3, , , , 1

FLST, 5, 12, 4, ORDE, 12
FITEM, 5, 129
FITEM, 5, 130
FITEM, 5, 131
FITEM, 5, 132
FITEM, 5, 133
FITEM, 5, 134
FITEM, 5, 135
FITEM, 5, 136
FITEM, 5, 137
FITEM, 5, 138
FITEM, 5, 139
FITEM, 5, 140
CM, _Y, LINE
LSEL, , , , P51X
CM, _Y1, LINE
CMSEL, _Y
!*
LESIZE, _Y1, , , 18, , , , , 1

FLST, 5, 12, 5, ORDE, 12
FITEM, 5, 25
FITEM, 5, 26
FITEM, 5, 27
FITEM, 5, 28
FITEM, 5, 29

```

```

FITEM,5,30
FITEM,5,31
FITEM,5,32
FITEM,5,33
FITEM,5,34
FITEM,5,35
FITEM,5,36
ASEL,S,,P51X
aatt,1
type,1
MSHAPE,0,2D
MSHKEY,0
amesh,all

FLST,5,12,4,ORDE,12
FITEM,5,46
FITEM,5,50
FITEM,5,54
FITEM,5,58
FITEM,5,62
FITEM,5,66
FITEM,5,70
FITEM,5,74
FITEM,5,78
FITEM,5,82
FITEM,5,86
FITEM,5,90
CM,_Y,LINE
LSEL,, , ,P51X
CM,_Y1,LINE
CMSEL,,_Y
!*
LESIZE,_Y1, , ,20,3, , , ,1

FLST,5,12,4,ORDE,12
FITEM,5,141
FITEM,5,142
FITEM,5,143
FITEM,5,144
FITEM,5,145
FITEM,5,146
FITEM,5,147
FITEM,5,148
FITEM,5,149
FITEM,5,150
FITEM,5,151
FITEM,5,152
CM,_Y,LINE
LSEL,, , ,P51X
CM,_Y1,LINE
CMSEL,,_Y
!*
LESIZE,_Y1, , ,18, , , , ,1

FLST,5,12,5,ORDE,12
FITEM,5,13
FITEM,5,14
FITEM,5,15
FITEM,5,16
FITEM,5,17
FITEM,5,18
FITEM,5,19
FITEM,5,20
FITEM,5,21
FITEM,5,22
FITEM,5,23
FITEM,5,24
ASEL,S,,P51X
aatt,1
type,1
MSHAPE,0,2D
MSHKEY,0

```

```

amesh,all

FLST,5,12,4,ORDE,12
FITEM,5,47
FITEM,5,51
FITEM,5,55
FITEM,5,59
FITEM,5,63
FITEM,5,67
FITEM,5,71
FITEM,5,75
FITEM,5,79
FITEM,5,83
FITEM,5,87
FITEM,5,91
CM,_Y,LINE
LSEL, , , ,P51X
CM,_Y1,LINE
CMSEL, , _Y
!*
LESIZE, _Y1, , ,20,2, , , ,1
!*
FLST,5,24,4,ORDE,24
FITEM,5,30
FITEM,5,29
FITEM,5,23
FITEM,5,28
FITEM,5,27
FITEM,5,22
FITEM,5,26
FITEM,5,25
FITEM,5,21
FITEM,5,32
FITEM,5,31
FITEM,5,24
FITEM,5,98
FITEM,5,97
FITEM,5,88
FITEM,5,100
FITEM,5,99
FITEM,5,84
FITEM,5,94
FITEM,5,93
FITEM,5,2
FITEM,5,96
FITEM,5,95
FITEM,5,92
CM,_Y,LINE
LSEL, , , ,P51X
CM,_Y1,LINE
CMSEL, , _Y
!*
LESIZE, _Y1, , ,18, , , , ,1

FLST,5,12,4,ORDE,12
FITEM,5,101
FITEM,5,102
FITEM,5,103
FITEM,5,104
FITEM,5,105
FITEM,5,106
FITEM,5,107
FITEM,5,108
FITEM,5,109
FITEM,5,110
FITEM,5,111
FITEM,5,112
CM,_Y,LINE
LSEL, , , ,P51X
CM,_Y1,LINE
CMSEL, , _Y
!*

```

```

LESIZE,_Y1,,,1,1,,,1

FLST,5,12,5,ORDE,12
FITEM,5,1
FITEM,5,2
FITEM,5,3
FITEM,5,4
FITEM,5,5
FITEM,5,6
FITEM,5,7
FITEM,5,8
FITEM,5,9
FITEM,5,10
FITEM,5,11
FITEM,5,12
ASEL,S,,P51X
aatt,1
type,1
MSHAPE,0,2D
MSHKEY,0
amesh,all

FLST,5,12,5,ORDE,12
FITEM,5,58
FITEM,5,59
FITEM,5,60
FITEM,5,61
FITEM,5,62
FITEM,5,63
FITEM,5,64
FITEM,5,65
FITEM,5,66
FITEM,5,67
FITEM,5,68
FITEM,5,69
ASEL,S,,P51X
aatt,1
type,3
MSHAPE,0,2D
MSHKEY,0
amesh,all

/reset
alls
NUMCMP,ALL
numm,node,1e-10
numm,kp,1e-10
!
/reset
!
eplo

!!!!!!!!!!!!!!!!!!!!!!!!!!!!Infinte Flag on Nodes!!!!!!!!!!!!!!!!!!!!!!!!!!!!
!
CSYS,1
NSSEL,S,LOC,X,r2
SF,ALL,INF

!!!!!!!!!!!!!!!!!!!!!!!!!!!!Coupling DOF's nur Volt!!!!!!!!!!!!!!!!!!!!!!!!!!!!
!
esel,s,mat,,2
eplo
ASEL,S,,, 55
NSLA,S,1
nplot
!
cp,1,volt,all

!!!!!!!!!!!!!!!!!!!!!!!!!!!!Total Current n*ip on Coil Node!!!!!!!!!!!!!!
/SOL
FLST,2,1,1,ORDE,1
FITEM,2,51

```

```

/GO
!*
F,P51X,AMPS,n*0.42

ASEL,S,, , 56
NSLA,S,1
nplot
!
cp,2,volt,all
FLST,2,1,1,ORDE,1
FITEM,2,294
/GO
!*
F,P51X,AMPS,-n*0.42

alls

fini
!
!
/SOLU
ALLSEL,ALL
!*
ANTYPE,3
HARFRQ,125000,0,
NSUBST, ,
KBC,0
!*
/STATUS,SOLU
SOLVE
save
!
FINISH

!
/POST1
!
SET,LIST

SET,FIRST
!
/PLOPTS,INFO,1
/PLOPTS,LEG1,1
/PLOPTS,LEG2,0
/PLOPTS,LEG3,1
/PLOPTS,FRAME,1
/PLOPTS,TITLE,1
/PLOPTS,MINM,1
/PLOPTS,FILE,0
/PLOPTS,LOGO,0
/PLOPTS,WINS,0
/PLOPTS,WP,0
/PLOPTS,DATE,1
/TRIAD,ORIG
!
!
PLF2D,60,0,10,1

```

3. Suspension modelling

```

/BATCH
/COM,ANSYS RELEASE 11.0 UP20070125 13:26:26 07/11/2007
/input,menust,tmp,",,,,,,,,,,,,,1
/GRA,POWER
/GST,ON
/PLO,INFO,3
/GRO,CURL,ON
/CPLANE,1
/REPLOT,RESIZE
WPSTYLE,,,,,,,,0
!*

```



```

/NOPR
KEYW,MAGNOD,1
/GO
/UNITS,SI
!
/FILNAME,Suspensions,0
/title,Plane Model of Suspension Parts
/PREP7
EMUNIT,MKS
!
!*****
!Parameters
!*****
*SET,l,40e-3
*SET,r,2.85e-3
*SET,n,190
*SET,d_wire,0.17e-3
*SET,l_wire,n*d_wire
*SET,r1,1.5
*SET,r2,1.55
*SET,copper,1
*SET,aluminium,2.72e-8
*SET,steel,1.7e-7
*SET,ip,0.42
*SET,g1,4e-2
*SET,g2,1e-2
*SET,g3,9e-2
*SET,g4,14e-2
*SET,g5,8e-2
*SET,g6,1.5e-2
*SET,a,27.5e-2
*SET,b,3.75e-2
*SET,c,22e-2
*SET,e,84e-2
*SET,f,8e-2
*SET,h,2.5e-2
*SET,i,68e-2
*SET,d,36e-2
!*****
!Element Types
!*****
!
ET,1,PLANE53
!*
KEYOPT,1,1,0
KEYOPT,1,2,0
KEYOPT,1,3,0
KEYOPT,1,4,0
KEYOPT,1,5,0
KEYOPT,1,7,0
!
ET,2,PLANE53
!*
KEYOPT,2,1,1
KEYOPT,2,2,0
KEYOPT,2,3,0
KEYOPT,2,4,0
KEYOPT,2,5,0
KEYOPT,2,7,0
!
ET,3,INFIN110
!*
KEYOPT,3,1,0
KEYOPT,3,2,1
KEYOPT,3,3,0
KEYOPT,3,6,0
!*****
!Material Properties
!*****
MPTEMP,,,,,,,,
MPTEMP,1,0
MPDATA,MURX,1,,1

```

```

!
MPTEMP,,,,,,,,
MPTEMP,1,0
MPDATA,MURX,2,,copper
MPDATA,RSVX,2,,1.72e-8
!
MPTEMP,,,,,,,,
MPTEMP,1,0
MPDATA,RSVX,3,,5
!
TB,BH,3,1,16,
TBTEMP,0
TBPT,,15,0.2
TBPT,,19,0.25
TBPT,,25,0.285
TBPT,,29,0.3
TBPT,,48,0.35
TBPT,,75,0.39
TBPT,,90,0.4
TBPT,,100,0.405
TBPT,,125,0.415
TBPT,,150,0.423
TBPT,,175,0.425
TBPT,,200,0.428
TBPT,,225,0.43
TBPT,,250,0.431
TBPT,,500,0.435
TBPT,,1000,0.44
!
!MPTEMP,,,,,,,,
!MPTEMP,1,0
!MPDATA,MURX,4,,1000
!MPDATA,RSVX,4,,aluminium
!
MPTEMP,,,,,,,,
MPTEMP,1,0
MPDATA,MURX,4,,10000
MPDATA,RSVX,4,,steel
!
!*****
!Building Geometrie
!*****
!
/PNUM,KP,1
/PNUM,LINE,1
K,,r,l/2,,
K,,r,-l/2,,
K,,-r,-l/2,,
K,,-r,l/2,,
k,,r,l_wire/2,,
k,,r,-l_wire/2,,
FLST,3,4,3,ORDE,4
FITEM,3,1
FITEM,3,-2
FITEM,3,5
FITEM,3,-6
KGEN,2,P51X, , , d_wire, , , ,0
k,,-r,l_wire/2,,
k,,-r,-l_wire/2,,
FLST,3,4,3,ORDE,4
FITEM,3,3
FITEM,3,-4
FITEM,3,11
FITEM,3,-12
KGEN,2,P51X, , , -d_wire , , , ,0
LSTR,1,5
LSTR,5,6
LSTR,6,2
LSTR,2,3
LSTR,3,12
LSTR,12,11
LSTR,11,4

```

LSTR,4,1
 LSTR,5,9
 LSTR,9,10
 LSTR,10,6
 LSTR,11,15
 LSTR,15,16
 LSTR,16,12
 LSTR,1,7
 LSTR,7,9
 LSTR,2,8
 LSTR,8,10
 LSTR,3,13
 LSTR,13,16
 LSTR,4,14
 LSTR,14,15
 LSTR,6,12
 LSTR,5,11
 K, ,d,,,
 K, ,d+h,,,
 K, ,d,c,,,
 FLST,3,1,3,ORDE,1
 FITEM,3,19
 KGEN,2,P51X, , , g6,,, ,0
 FLST,3,1,3,ORDE,1
 FITEM,3,20
 KGEN,2,P51X, , , b,,, ,0
 FLST,3,1,3,ORDE,1
 FITEM,3,19
 KGEN,2,P51X, , , -b,,, ,0
 FLST,3,4,3,ORDE,2
 FITEM,3,19
 FITEM,3,-22
 KGEN,2,P51X, , , e , , ,0
 LSTR,17,19
 LSTR,19,22
 LSTR,20,21
 LSTR,22,26
 LSTR,26,23
 LSTR,21,25
 LSTR,24,25
 FLST,3,1,3,ORDE,1
 FITEM,3,20
 KGEN,2,P51X, , , a,f, , ,0
 FLST,3,1,3,ORDE,1
 FITEM,3,27
 KGEN,2,P51X, , , -0.015,,, ,0
 LSTR,27,18
 FLST,3,1,3,ORDE,1
 FITEM,3,20
 KGEN,2,P51X, , , -c+1.5e-2, , ,0
 LSTR,28,29
 LSTR,29,20
 LSTR,17,18
 FLST,3,1,3,ORDE,1
 FITEM,3,27
 KGEN,2,P51X, , , 2.5e-2,,, ,0
 FLST,3,3,3,ORDE,3
 FITEM,3,27
 FITEM,3,-28
 FITEM,3,30
 KGEN,2,P51X, , , i, , ,0
 FLST,3,1,3,ORDE,1
 FITEM,3,29
 KGEN,2,P51X, , , e+2*c-3e-2, , ,0
 FLST,3,2,3,ORDE,2
 FITEM,3,17
 FITEM,3,-18
 KGEN,2,P51X, , , e+2*c, , ,0
 LSTR,30,33
 LSTR,28,32
 LSTR,27,30
 LSTR,31,33

LSTR,31,36
 LSTR,32,34
 LSTR,24,34
 LSTR,23,35
 LSTR,35,36
 FLST,2,2,8
 FITEM,2,0,0,0
 FITEM,2,r1,0,0
 CIRCLE,P51X
 FLST,3,4,4,ORDE,2
 FITEM,3,45
 FITEM,3,-48
 LGEN, ,P51X, , ,d,c+e/2, , , ,1
 LDIV,46, , , ,2,0
 LDIV,45, , , ,2,0
 LDIV,48, , , ,2,0
 LDIV,47, , , ,3,0
 FLST,2,1,4,ORDE,1
 FITEM,2,28
 LDIV,P51X,0.5, ,2,0
 FLST,2,1,4,ORDE,1
 FITEM,2,36
 LDIV,P51X,0.5, ,2,0
 LSTR,47,37
 LSTR,46,39
 LSTR,35,38
 LSTR,17,40
 LSTR,33,42
 LSTR,30,43
 LSTR,26,41
 LDIV,52, , , ,3,0
 LSTR,22,49
 FLST,2,3,4,ORDE,3
 FITEM,2,47
 FITEM,2,52
 FITEM,2,63
 LCOMB,P51X, ,0
 FLST,2,2,4,ORDE,2
 FITEM,2,53
 FITEM,2,64
 LCOMB,P51X, ,0
 LDIV,58, , , ,3,0
 LDIV,59, , , ,3,0
 LDIV,60, , , ,3,0
 LDIV,61, , , ,3,0
 LDIV,56, , , ,3,0
 LDIV,57, , , ,4,0
 LDIV,62, , , ,4,0
 LDIV,65, , , ,4,0
 LSTR,57,60
 LSTR,57,63
 LSTR,60,35
 LSTR,63,17
 LSTR,58,61
 LSTR,58,64
 LSTR,61,44
 LSTR,64,48
 LSTR,44,51
 LSTR,48,53
 LSTR,51,55
 LSTR,53,55
 LSTR,59,62
 LSTR,59,65
 LSTR,62,45
 LSTR,65,50
 LSTR,45,52
 LSTR,50,54
 LSTR,52,56
 LSTR,54,56
 FLST,2,2,8
 FITEM,2,0,0,0
 FITEM,2,r2,0,0

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CIRCLE,P51X
FLST,3,4,4,ORDE,2
FITEM,3,102
FITEM,3,-105
LGEN, ,P51X, , ,d,c+e/2, , , ,1
LDIV,102, , ,2,0
LDIV,103, , ,2,0
LDIV,105, , ,2,0
LDIV,104, , ,3,0
LDIV,109, , ,3,0

FLST,2,3,4,ORDE,3
FITEM,2,104
FITEM,2,109
FITEM,2,111
LCOB,P51X, ,0
FLST,2,2,4,ORDE,2
FITEM,2,112
FITEM,2,110
LCOB,P51X, ,0
LSTR,38,67
LSTR,42,70
LSTR,37,66
LSTR,43,72
LSTR,40,69
LSTR,49,76
LSTR,39,68
LSTR,41,71
LSTR, 23, 24
LSTR, 19, 20
LSTR, 17, 29
LSTR, 18, 29
LSTR, 35, 34
LSTR, 36, 34
LSTR, 32, 31
LSTR, 28, 27
!
!!!!!!!!!!!!!!!!!!!!Areas & Meshing!!!!!!!!!!!!!!!!!!!!
/PNUM,AREA,1
!
!
!*****Antenna Meshing*****
!
FLST,2,4,4
FITEM,2,13
FITEM,2,6
FITEM,2,12
FITEM,2,14
AL,P51X
FLST,2,4,4
FITEM,2,10
FITEM,2,2
FITEM,2,11
FITEM,2,9
AL,P51X
FLST,2,4,4
FITEM,2,7
FITEM,2,8
FITEM,2,1
FITEM,2,24
AL,P51X
FLST,2,4,4
FITEM,2,6
FITEM,2,24
FITEM,2,2
FITEM,2,23
AL,P51X
FLST,2,4,4
FITEM,2,23
FITEM,2,3
FITEM,2,4
FITEM,2,5

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AL,P51X
FLST,2,4,4
FITEM,2,7
FITEM,2,22
FITEM,2,21
FITEM,2,12
AL,P51X
FLST,2,4,4
FITEM,2,1
FITEM,2,16
FITEM,2,15
FITEM,2,9
AL,P51X
FLST,2,4,4
FITEM,2,20
FITEM,2,5
FITEM,2,14
FITEM,2,19
AL,P51X
FLST,2,4,4
FITEM,2,3
FITEM,2,18
FITEM,2,17
FITEM,2,11
AL,P51X

FLST,5,4,4,ORDE,4
FITEM,5,4
FITEM,5,23
FITEM,5,24
FITEM,5,8
CM,_Y,LINE
LSEL, , , ,P51X
CM,_Y1,LINE
CMSEL, , ,_Y
!*
LESIZE,_Y1, , ,20, , , ,1

FLST,5,8,4,ORDE,8
FITEM,5,3
FITEM,5,18
FITEM,5,5
FITEM,5,20
FITEM,5,16
FITEM,5,1
FITEM,5,7
FITEM,5,22
CM,_Y,LINE
LSEL, , , ,P51X
CM,_Y1,LINE
CMSEL, , ,_Y
!*
LESIZE,_Y1, , ,20, , , ,1

FLST,5,4,4,ORDE,4
FITEM,5,2
FITEM,5,6
FITEM,5,13
FITEM,5,10
CM,_Y,LINE
LSEL, , , ,P51X
CM,_Y1,LINE
CMSEL, , ,_Y
!*
LESIZE,_Y1, , ,120, , , ,1

FLST,5,8,4,ORDE,8
FITEM,5,21
FITEM,5,12
FITEM,5,15
FITEM,5,9
FITEM,5,14

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FITEM,5,19
FITEM,5,11
FITEM,5,17
CM,_Y,LINE
LSEL,,,P51X
CM,_Y1,LINE
CMSEL,,_Y
!*
LESIZE,_Y1,,,2,,,,,1
!
FLST,5,2,5,ORDE,2
FITEM,5,1
FITEM,5,2
ASEL,S,,,P51X
aatt,2
type,2
amesh,all
!
FLST,5,3,5,ORDE,3
FITEM,5,3
FITEM,5,4
FITEM,5,5
ASEL,S,,,P51X
aatt,3
type,1
amesh,all
!
FLST,5,4,5,ORDE,4
FITEM,5,6
FITEM,5,7
FITEM,5,8
FITEM,5,9
ASEL,S,,,P51X
aatt,1
type,1
amesh,all
!
!*****Suspension Meshing*****
!
FLST,2,9,4
FITEM,2,54
FITEM,2,28
FITEM,2,26
FITEM,2,119
FITEM,2,27
FITEM,2,30
FITEM,2,31
FITEM,2,118
FITEM,2,29
AL,P51X
FLST,2,4,4
FITEM,2,118
FITEM,2,42
FITEM,2,43
FITEM,2,122
AL,P51X
FLST,2,3,4
FITEM,2,122
FITEM,2,44
FITEM,2,123
AL,P51X
FLST,2,4,4
FITEM,2,123
FITEM,2,40
FITEM,2,41
FITEM,2,124
AL,P51X
FLST,2,7,4
FITEM,2,124
FITEM,2,39
FITEM,2,55
FITEM,2,36

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FITEM,2,38
FITEM,2,125
FITEM,2,37
AL,P51X
FLST,2,4,4
FITEM,2,125
FITEM,2,33
FITEM,2,32
FITEM,2,121
AL,P51X
FLST,2,3,4
FITEM,2,35
FITEM,2,121
FITEM,2,120
AL,P51X
FLST,2,4,4
FITEM,2,120
FITEM,2,25
FITEM,2,34
FITEM,2,119
AL,P51X

FLST,5,2,4,ORDE,2
FITEM,5,54
FITEM,5,28
CM,_Y,LINE
LSEL, , , ,P51X
CM,_Y1,LINE
CMSEL,,_Y
!*
LESIZE,_Y1, , ,100, , , ,1

FLST,5,1,4,ORDE,1
FITEM,5,30
CM,_Y,LINE
LSEL, , , ,P51X
CM,_Y1,LINE
CMSEL,,_Y
!*
LESIZE,_Y1, , ,200, , , ,1

FLST,5,4,4,ORDE,4
FITEM,5,26
FITEM,5,27
FITEM,5,29
FITEM,5,31
CM,_Y,LINE
LSEL, , , ,P51X
CM,_Y1,LINE
CMSEL,,_Y
!*
LESIZE,_Y1, , ,12, , , ,1

FLST,5,2,4,ORDE,2
FITEM,5,118
FITEM,5,119
CM,_Y,LINE
LSEL, , , ,P51X
CM,_Y1,LINE
CMSEL,,_Y
!*
LESIZE,_Y1, , ,6, , , ,1

FLST,5,4,4,ORDE,4
FITEM,5,42
FITEM,5,43
FITEM,5,25
FITEM,5,34
CM,_Y,LINE
LSEL, , , ,P51X
CM,_Y1,LINE
CMSEL,,_Y

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!*
LESIZE,_Y1,,,80,,,,,1

FLST,5,6,4,ORDE,6
FITEM,5,44
FITEM,5,122
FITEM,5,123
FITEM,5,35
FITEM,5,120
FITEM,5,121
CM,_Y,LINE
LSEL,,,,P51X
CM,_Y1,LINE
CMSEL,,_Y
!*
LESIZE,_Y1,,,10,,,,,1

FLST,5,4,4,ORDE,4
FITEM,5,40
FITEM,5,41
FITEM,5,32
FITEM,5,33
CM,_Y,LINE
LSEL,,,,P51X
CM,_Y1,LINE
CMSEL,,_Y
!*
LESIZE,_Y1,,,140,,,,,1

FLST,5,2,4,ORDE,2
FITEM,5,39
FITEM,5,38
CM,_Y,LINE
LSEL,,,,P51X
CM,_Y1,LINE
CMSEL,,_Y
!*
LESIZE,_Y1,,,8,,,,,1

FLST,5,2,4,ORDE,2
FITEM,5,124
FITEM,5,125
CM,_Y,LINE
LSEL,,,,P51X
CM,_Y1,LINE
CMSEL,,_Y
!*
LESIZE,_Y1,,,6,,,,,1

FLST,5,1,4,ORDE,1
FITEM,5,36
CM,_Y,LINE
LSEL,,,,P51X
CM,_Y1,LINE
CMSEL,,_Y
!*
LESIZE,_Y1,,,40,5,,,,,1

FLST,5,1,4,ORDE,1
FITEM,5,55
CM,_Y,LINE
LSEL,,,,P51X
CM,_Y1,LINE
CMSEL,,_Y
!*
LESIZE,_Y1,,,50,0.2,,,,,1

FLST,5,1,4,ORDE,1
FITEM,5,37
CM,_Y,LINE
LSEL,,,,P51X
CM,_Y1,LINE

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CMSEL,,_Y
!*
LESIZE,_Y1,,100,-5,,,1

FLST,5,8,5,ORDE,2
FITEM,5,10
FITEM,5,-17
ASEL,S,,,P51X
aatt,4
type,1
amesh,all
!
!
!*****Air Meshing*****
!
FLST,2,8,4
FITEM,2,30
FITEM,2,31
FITEM,2,42
FITEM,2,41
FITEM,2,37
FITEM,2,33
FITEM,2,34
FITEM,2,27
AL,P51X
FLST,2,4,4
FITEM,2,84
FITEM,2,62
FITEM,2,29
FITEM,2,43
AL,P51X
FLST,2,4,4
FITEM,2,62
FITEM,2,82
FITEM,2,57
FITEM,2,54
AL,P51X
FLST,2,4,4
FITEM,2,57
FITEM,2,83
FITEM,2,65
FITEM,2,28
AL,P51X
FLST,2,4,4
FITEM,2,85
FITEM,2,65
FITEM,2,25
FITEM,2,26
AL,P51X
FLST,2,4,4
FITEM,2,73
FITEM,2,86
FITEM,2,76
FITEM,2,82
AL,P51X
FLST,2,4,4
FITEM,2,76
FITEM,2,88
FITEM,2,84
FITEM,2,58
AL,P51X
FLST,2,6,4
FITEM,2,58
FITEM,2,90
FITEM,2,60
FITEM,2,39
FITEM,2,40
FITEM,2,44
AL,P51X
FLST,2,4,4
FITEM,2,60
FITEM,2,92

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FITEM,2,56
FITEM,2,55
AL,P51X
FLST,2,4,4
FITEM,2,56
FITEM,2,93
FITEM,2,61
FITEM,2,36
AL,P51X
FLST,2,6,4
FITEM,2,61
FITEM,2,91
FITEM,2,59
FITEM,2,35
FITEM,2,32
FITEM,2,38
AL,P51X
FLST,2,4,4
FITEM,2,89
FITEM,2,79
FITEM,2,85
FITEM,2,59
AL,P51X
FLST,2,16,4
FITEM,2,87
FITEM,2,73
FITEM,2,83
FITEM,2,79
FITEM,2,21
FITEM,2,8
FITEM,2,15
FITEM,2,16
FITEM,2,10
FITEM,2,18
FITEM,2,17
FITEM,2,4
FITEM,2,19
FITEM,2,20
FITEM,2,13
FITEM,2,22
AL,P51X
FLST,2,4,4
FITEM,2,74
FITEM,2,94
FITEM,2,77
FITEM,2,86
AL,P51X
FLST,2,4,4
FITEM,2,77
FITEM,2,96
FITEM,2,52
FITEM,2,88
AL,P51X
FLST,2,4,4
FITEM,2,52
FITEM,2,98
FITEM,2,67
FITEM,2,90
AL,P51X
FLST,2,4,4
FITEM,2,67
FITEM,2,100
FITEM,2,71
FITEM,2,92
AL,P51X
FLST,2,4,4
FITEM,2,71
FITEM,2,93
FITEM,2,69
FITEM,2,101
AL,P51X
FLST,2,4,4

FITEM,2,69
FITEM,2,99
FITEM,2,64
FITEM,2,91
AL,P51X
FLST,2,4,4
FITEM,2,64
FITEM,2,97
FITEM,2,80
FITEM,2,89
AL,P51X
FLST,2,4,4
FITEM,2,80
FITEM,2,95
FITEM,2,74
FITEM,2,87
AL,P51X
FLST,2,4,4
FITEM,2,75
FITEM,2,78
FITEM,2,49
FITEM,2,94
AL,P51X
FLST,2,4,4
FITEM,2,78
FITEM,2,96
FITEM,2,63
FITEM,2,46
AL,P51X
FLST,2,4,4
FITEM,2,63
FITEM,2,50
FITEM,2,68
FITEM,2,98
AL,P51X
FLST,2,4,4
FITEM,2,68
FITEM,2,100
FITEM,2,72
FITEM,2,45
AL,P51X
FLST,2,4,4
FITEM,2,72
FITEM,2,101
FITEM,2,70
FITEM,2,51
AL,P51X
FLST,2,4,4
FITEM,2,70
FITEM,2,99
FITEM,2,48
FITEM,2,66
AL,P51X
FLST,2,4,4
FITEM,2,66
FITEM,2,97
FITEM,2,81
FITEM,2,53
AL,P51X
FLST,2,4,4
FITEM,2,81
FITEM,2,47
FITEM,2,75
FITEM,2,95
AL,P51X
FLST,2,4,4
FITEM,2,116
FITEM,2,117
FITEM,2,107
FITEM,2,49
AL,P51X
FLST,2,4,4

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FITEM,2,117
FITEM,2,103
FITEM,2,46
FITEM,2,109
AL,P51X
FLST,2,4,4
FITEM,2,109
FITEM,2,50
FITEM,2,106
FITEM,2,111
AL,P51X
FLST,2,4,4
FITEM,2,111
FITEM,2,112
FITEM,2,45
FITEM,2,102
AL,P51X
FLST,2,4,4
FITEM,2,112
FITEM,2,113
FITEM,2,51
FITEM,2,108
AL,P51X
FLST,2,4,4
FITEM,2,113
FITEM,2,114
FITEM,2,48
FITEM,2,105
AL,P51X
FLST,2,4,4
FITEM,2,114
FITEM,2,115
FITEM,2,110
FITEM,2,53
AL,P51X
FLST,2,4,4
FITEM,2,115
FITEM,2,116
FITEM,2,47
FITEM,2,104
AL,P51X
/PNUM,AREA,1

ASEL,S,,, 18
aatt,1
type,1
amesh,all

FLST,5,4,4,ORDE,4
FITEM,5,62
FITEM,5,65
FITEM,5,84
FITEM,5,85
CM,_Y,LINE
LSEL,,,,P51X
CM,_Y1,LINE
CMSEL,,_Y
!*
LESIZE,_Y1,,,80,,,,,1

FLST,5,2,4,ORDE,2
FITEM,5,82
FITEM,5,83
CM,_Y,LINE
LSEL,,,,P51X
CM,_Y1,LINE
CMSEL,,_Y
!*
LESIZE,_Y1,,,60,0.2,,,,,1

FLST,5,1,4,ORDE,1
FITEM,5,57

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CM,_Y,LINE
LSEL, , , ,P51X
CM,_Y1,LINE
CMSEL, ,_Y
!*
LESIZE,_Y1, , ,40,5, , , ,1

FLST,5,4,5,ORDE,2
FITEM,5,19
FITEM,5,-22
ASEL,S, , ,P51X
aatt,1
type,1
amesh,all

FLST,5,4,4,ORDE,4
FITEM,5,58
FITEM,5,59
FITEM,5,76
FITEM,5,79
CM,_Y,LINE
LSEL, , , ,P51X
CM,_Y1,LINE
CMSEL, ,_Y
!*
LESIZE,_Y1, , ,40,5, , , ,1

FLST,5,1,4,ORDE,1
FITEM,5,73
CM,_Y,LINE
LSEL, , , ,P51X
CM,_Y1,LINE
CMSEL, ,_Y
!*
LESIZE,_Y1, , ,20,2, , , ,1

FLST,5,3,4,ORDE,3
FITEM,5,60
FITEM,5,61
FITEM,5,56
CM,_Y,LINE
LSEL, , , ,P51X
CM,_Y1,LINE
CMSEL, ,_Y
!*
LESIZE,_Y1, , ,40,5, , , ,1

FLST,5,2,4,ORDE,2
FITEM,5,88
FITEM,5,89
CM,_Y,LINE
LSEL, , , ,P51X
CM,_Y1,LINE
CMSEL, ,_Y
!*
LESIZE,_Y1, , ,40,0.7, , , ,1

FLST,5,2,4,ORDE,2
FITEM,5,86
FITEM,5,87
CM,_Y,LINE
LSEL, , , ,P51X
CM,_Y1,LINE
CMSEL, ,_Y
!*
LESIZE,_Y1, , ,40,0.7, , , ,1

FLST,5,2,4,ORDE,2
FITEM,5,90
FITEM,5,91
CM,_Y,LINE
LSEL, , , ,P51X

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CM,_Y1,LINE
CMSEL,,_Y
!*
LESIZE,_Y1,, ,40,2, , , ,1

FLST,5,2,4,ORDE,2
FITEM,5,92
FITEM,5,93
CM,_Y,LINE
LSEL, , , ,P51X
CM,_Y1,LINE
CMSEL,,_Y
!*
LESIZE,_Y1,, ,30, , , , ,1

FLST,5,8,5,ORDE,2
FITEM,5,23
FITEM,5,-30
ASEL,S, , ,P51X
aatt,1
type,1
amesh,all

FLST,5,8,4,ORDE,8
FITEM,5,52
FITEM,5,67
FITEM,5,71
FITEM,5,69
FITEM,5,64
FITEM,5,80
FITEM,5,74
FITEM,5,77
CM,_Y,LINE
LSEL, , , ,P51X
CM,_Y1,LINE
CMSEL,,_Y
!*
LESIZE,_Y1,, ,16,3, , , ,1

FLST,5,4,4,ORDE,4
FITEM,5,59
FITEM,5,61
FITEM,5,56
FITEM,5,60
CM,_Y,LINE
LSEL, , , ,P51X
CM,_Y1,LINE
CMSEL,,_Y
!*
LESIZE,_Y1,, ,16,2, , , ,1

FLST,5,8,4,ORDE,2
FITEM,5,94
FITEM,5,-101
CM,_Y,LINE
LSEL, , , ,P51X
CM,_Y1,LINE
CMSEL,,_Y
!*
LESIZE,_Y1,, ,22, , , , ,1

FLST,5,8,5,ORDE,2
FITEM,5,31
FITEM,5,-38
ASEL,S, , ,P51X
aatt,1
type,1
amesh,all

FLST,5,8,4,ORDE,8
FITEM,5,75
FITEM,5,78

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FITEM,5,63
FITEM,5,68
FITEM,5,72
FITEM,5,70
FITEM,5,66
FITEM,5,81
CM,_Y,LINE
LSEL,,,P51X
CM,_Y1,LINE
CMSEL,,_Y
!*
LESIZE,_Y1,,,16,2,,,1

FLST,5,16,4,ORDE,6
FITEM,5,45
FITEM,5,-51
FITEM,5,53
FITEM,5,102
FITEM,5,-108
FITEM,5,110
CM,_Y,LINE
LSEL,,,P51X
CM,_Y1,LINE
CMSEL,,_Y
!*
LESIZE,_Y1,,,20,,,,1

FLST,5,8,4,ORDE,3
FITEM,5,109
FITEM,5,111
FITEM,5,-117
CM,_Y,LINE
LSEL,,,P51X
CM,_Y1,LINE
CMSEL,,_Y
!*
LESIZE,_Y1,,,1,,,,1

FLST,5,8,5,ORDE,2
FITEM,5,39
FITEM,5,-46
ASEL,S,,,P51X
aatt,1
type,1
amesh,all

FLST,5,8,5,ORDE,2
FITEM,5,47
FITEM,5,-54
ASEL,S,,,P51X
aatt,1
type,1
amesh,all

alls
!
!*****
!
!!!!!!!!!!!!!!!!!!!!Infinte Flag on Nodes!!!!!!!!!!!!!!!!!!!!
!
NSEL,S,EXT
nplot
SF,ALL,INF
!
!*****Defining Loads*****
!
/SOLU
alls
eplot

ASEL,S,,, 1

```



```

NSLA,S,1
nplot
!
cp,1,volt,all
FLST,2,1,1,ORDE,1
FITEM,2,357
/GO
!*
F,P51X,AMPS,n*ip

ASEL,S,,, 2
NSLA,S,1
nplot
!
cp,2,volt,all
FLST,2,1,1,ORDE,1
FITEM,2,1312
/GO
!*
F,P51X,AMPS,-n*ip
alls
fini
!
/SOLU
ALLSEL,ALL
!*
ANTYPE,3
HARFRQ,125000,0,
NSUBST,,,
KBC,0
!*
/STATUS,SOLU
SOLVE
save
!
FINISH
!
/POST1
SET,LIST
SET,FIRST
!
!
PLF2D,126,0,10,1
/WINDOW,1,FULL
/REPLOT

```

4. 3-D modelling

```

/BATCH
/COM,ANSYS RELEASE 11.0 UP20070125 13:22:56 07/24/2007
/input,menust,tmp,",,,,,,,,,,,,,1
/GRA,POWER
/GST,ON
/PLO,INFO,3
/GRO,CURL,ON
/CPLANE,1
/REPLOT,RESIZE
WPSTYLE,,,,,,,,0
!*
/NOPR
/PMETH,OFF,1
KEYW,PR_SET,1
KEYW,PR_STRUC,0
KEYW,PR_THERM,0
KEYW,PR_FLUID,0
KEYW,PR_ELMAG,1
KEYW,MAGNOD,1
KEYW,MAGEDG,0

```

```

KEYW,MAGHFE,0
KEYW,MAGELC,0
KEYW,PR_MULTI,0
KEYW,PR_CFD,0
/FILNAME,3d,0
/title,Trigger Antenna 3-d modeling, Axisymmetric
/GO
!*
/COM,
/COM,Preferences for GUI filtering have been set to display:
/COM, Magnetic-Nodal
!*
/PREP7
!
!*****
!Parameters
!*****
*SET,l,40e-3
*SET,r,2.85e-3
*SET,diam,2*r
*SET,n,180
*SET,d_wire,0.17e-3
*SET,l_wire,n*d_wire
*SET,r1,1.1
*SET,r2,1.125
*SET,dl,3e-3
*SET,copper,1.72e-8
*SET,ferrite,50000
*SET,I,75.6
!*
!*****
!Element Types
!*****
!*
ET,1,SOLID97
!
ET,2,SOLID97
KEYOPT,2,1,6
!*
ET,3,INFIN111
KEYOPT,3,1,1
KEYOPT,3,2,0
KEYOPT,3,6,0
!*
ET,4,PLANE13
!*
!*****
!Material Properties
!*****
MPTEMP,,,,,,,,
MPTEMP,1,0
MPDATA,MURX,1,,1
!
MPTEMP,,,,,,,,
MPTEMP,1,0
MPDATA,MURX,2,,1
MPDATA,RSVX,2,,copper
!
MPTEMP,,,,,,,,
MPTEMP,1,0
MPDATA,MURX,3,,0.0073
MPDATA,RSVX,3,,ferrite
!
!*****
!Building Geometrie
!*****
!
/PNUM,KP,1
/PNUM,LINE,1
k,,,,
K,,r,,,
K,,,r,,

```

```

LARC,2,3,1,r
LSTR,1,2
LSTR,1,3
K,,r+d_wire,,,
K,,,r+d_wire,,
LARC,4,5,1,r+d_wire
LSTR,3,5
LSTR,2,4
lplot
K,,r1,,,
K,,,r1,,
LARC,6,7,1,r1
LSTR,5,7
LSTR,4,6
lplot
K,,r2,,,
K,,,r2,,
LARC,8,9,1,r2
LSTR,7,9
LSTR,6,8
lplot
FLST,5,2,4,ORDE,2
FITEM,5,2
FITEM,5,3
CM,_Y,LINE
LSEL,,,P51X
CM,_Y1,LINE
CMSEL,,-Y
!*
LESIZE,,-Y1,,,20,,,,,1

FLST,5,3,4,ORDE,3
FITEM,5,1
FITEM,5,4
FITEM,5,7
CM,_Y,LINE
LSEL,,,P51X
CM,_Y1,LINE
CMSEL,,-Y
!*
LESIZE,,-Y1,,,30,,,,,1

FLST,2,3,4
FITEM,2,1
FITEM,2,2
FITEM,2,3
AL,P51X

FLST,5,1,5,ORDE,1
FITEM,5,1
ASEL,S,,,P51X
aatt,3
type,4
MSHAPE,0,2D
MSHKEY,1
amesh,all

FLST,5,2,4,ORDE,2
FITEM,5,5
FITEM,5,6
CM,_Y,LINE
LSEL,,,P51X
CM,_Y1,LINE
CMSEL,,-Y
!*
LESIZE,,-Y1,,,4,,,,,1

FLST,2,4,4
FITEM,2,1
FITEM,2,4
FITEM,2,5
FITEM,2,6

```

AL,P51X

FLST,5,1,5,ORDE,1
FITEM,5,2
ASEL,S,,P51X
aatt,2
type,4
MSHAPE,0,2D
MSHKEY,1
amesh,all

FLST,5,2,4,ORDE,2
FITEM,5,8
FITEM,5,9
CM,_Y,LINE
LSEL,,,P51X
CM,_Y1,LINE
CMSEL,/_Y
!*
LESIZE,_Y1,,40,30,,,,1

FLST,5,2,4,ORDE,2
FITEM,5,7
FITEM,5,10
CM,_Y,LINE
LSEL,,,P51X
CM,_Y1,LINE
CMSEL,/_Y
!*
LESIZE,_Y1,,20,,,,1

FLST,2,4,4
FITEM,2,7
FITEM,2,4
FITEM,2,8
FITEM,2,9
AL,P51X

FLST,5,1,5,ORDE,1
FITEM,5,3
ASEL,S,,P51X
aatt,1
type,4
MSHAPE,0,2D
MSHKEY,1
amesh,all

FLST,5,2,4,ORDE,2
FITEM,5,11
FITEM,5,12
CM,_Y,LINE
LSEL,,,P51X
CM,_Y1,LINE
CMSEL,/_Y
!*
LESIZE,_Y1,,1,,,,1

FLST,2,4,4
FITEM,2,11
FITEM,2,12
FITEM,2,10
FITEM,2,7
AL,P51X

FLST,5,1,5,ORDE,1
FITEM,5,4
ASEL,S,,P51X
aatt,1
type,4
MSHAPE,0,2D
MSHKEY,1
amesh,all

```

alls
/PNUM,mat,1
/VIEW, 1 ,1,1,1
/ANG, 1
eplo

ESIZE,0,20,
type,1
mat,3
FLST,2,1,5,ORDE,1
FITEM,2,1
VEXT,P51X, , ,0,0,l/2,,,,

ESIZE,0,20,
type,2
mat,2
FLST,2,1,5,ORDE,1
FITEM,2,2
VEXT,P51X, , ,0,0,l_wire/2,,,,
alls

asel,s,loc,z,l_wire/2,l_wire/2
ESIZE,0,4,
type,1
mat,1
VEXT,all, , ,0,0,l/2-l_wire/2,,,,

asel,s,loc,z,l/2,l/2
ESIZE,0,50,
type,1
mat,1
VEXT,all, , ,0,0,r1-l/2,,,,

asel,s,loc,z,0,0
ESIZE,0,60,
type,1
mat,1
FLST,2,1,5,ORDE,1
FITEM,2,3
VEXT,P51X, , ,0,0,r1,,,,

ESIZE,0,60,
type,3
mat,1
FLST,2,1,5,ORDE,1
FITEM,2,4
VEXT,P51X, , ,0,0,r1,,,,
alls

asel,s,loc,z,r1,r1
ESIZE,0,1,
type,3
mat,1
FLST,2,3,5,ORDE,3
FITEM,2,28
FITEM,2,23
FITEM,2,19
VEXT,P51X, , ,0,0,r2-r1,,,,

alls
esel,s,type,,4
ESLA,S
aclear,all      !Plane13 deleting
alls
ETDEL,4

numm,node,1e-10
numm,kp,1e-10
NUMCMP,ALL
/reset
/PNUM,mat,1

```

```

/EDGE,1,0
/VIEW, 1 ,1,1,1
/ANG, 1
vplo
!*****
csys,0
NSEL,S,LOC,Z,r2
nplot
!
csys,1
nset,a,loc,x,r2
nplo
sf,all,inf

asum
!*
*GET,a,AREA,11,AREA
!*
vsum
vplot
!*
*GET,v,VOLU,2,VOLU
!*
CSYS,1
ESEL,S,MAT,,2
eplot
!*
R,1,a,180,v,0,0.42,0,
RMORE,8,1,
!*
*GET,N1,NODE,,NUM,MIN
D,N1,VOLT,0
NSLE,S
nplot
CP,1,VOLT,ALL
/SOL
FLST,2,1,1,ORDE,1
FITEM,2,17133
nplot
/GO
!*
F,P51X,AMPS,75.6

alls

ANTYPE,3
HARFRQ,125000,0,
NSUBST, ,
KBC,0
!*

```