

ANSYS



仿真
新时代

2017 ANSYS用户技术大会

中国·烟台

ANSYS EMC仿真设计思路及方法介绍

褚正浩 / 高级应用工程师

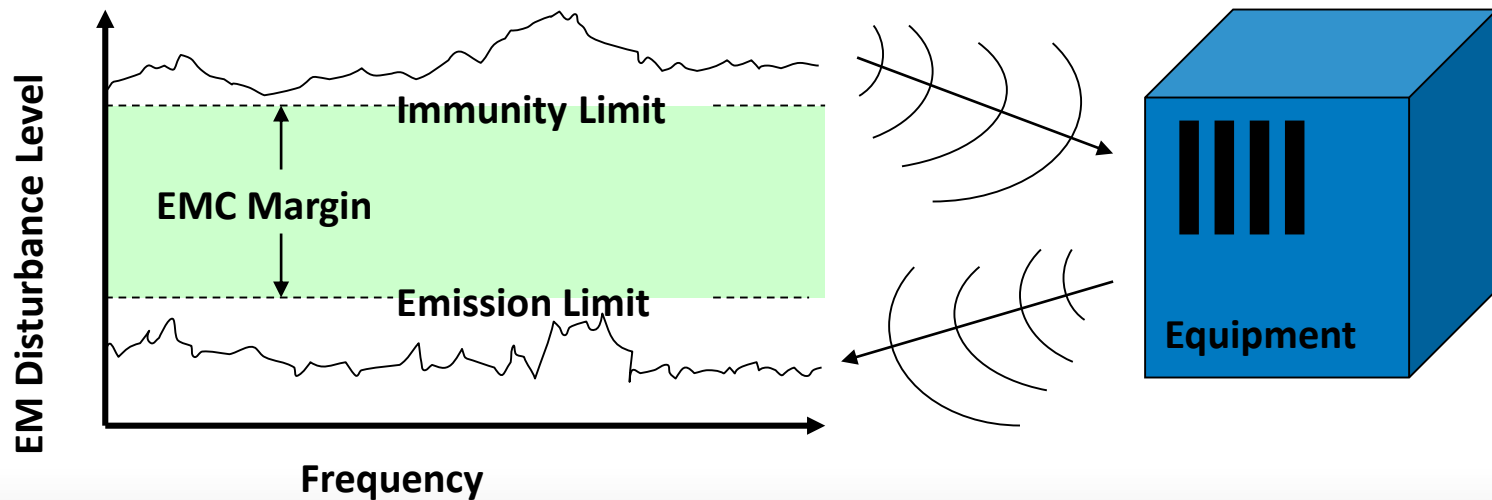
ANSYS China

目录

- **EMC设计需求**
- **ANSYS EMC仿真思路介绍**
- **ANSYS EMC仿真平台及能力介绍**

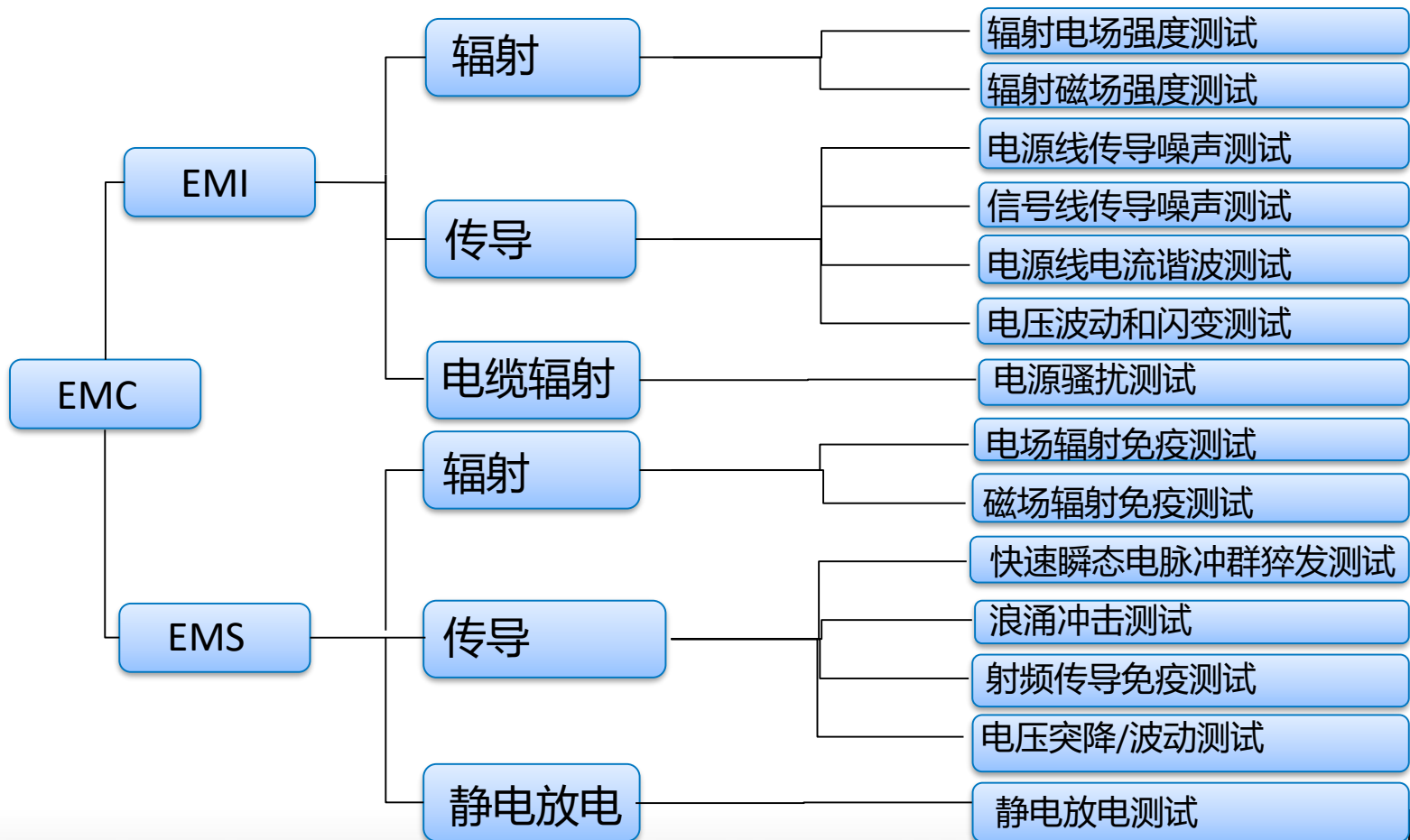
什么是EMC/EMI

- EMC电磁兼容:
主要研究预期外产生的电磁能量，及其传播和干扰。其目标是在有限的空间,时间和频谱资源下,各种设备共存而又不致引起性能降级
- EMI 电磁干扰:
指的是一个接收电路受到外部或其他电路所造成电磁干扰，以及由此现象引起的设备,传输通道或系统性能的下



电磁兼容标准

- 电磁兼容性测试分两类：电磁干扰（EMI）测试和电磁抗扰度（EMS）测试
- 依据相应的电磁兼容性标准和规范，测试在不同频率范围内，采用不同的方式进行



EMI/EMC 问题的难点

行业领域复杂

- 航空、航天、船舶、汽车、机车、通信、消费电子.....

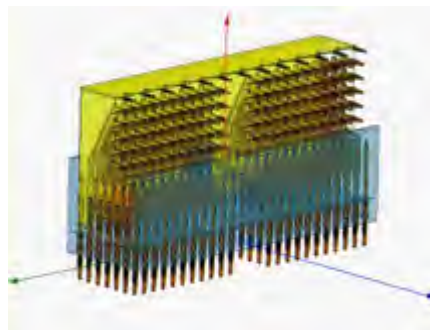
研究对象繁多

- 复杂系统、单机设备、电源、PCB、芯片封装.....

频段覆盖广泛

- 低频、高频
- 频域、时域
- 模拟、数字

系统中电子部件众多



高性能IC

复杂PCB

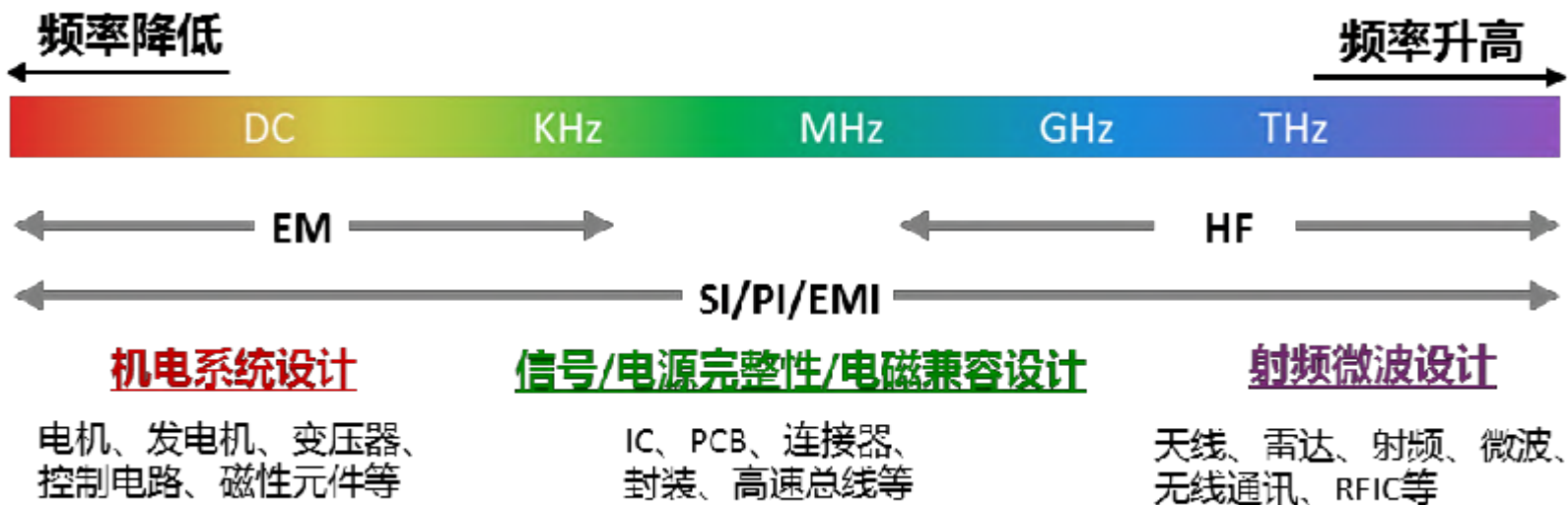
线缆接插件

机柜

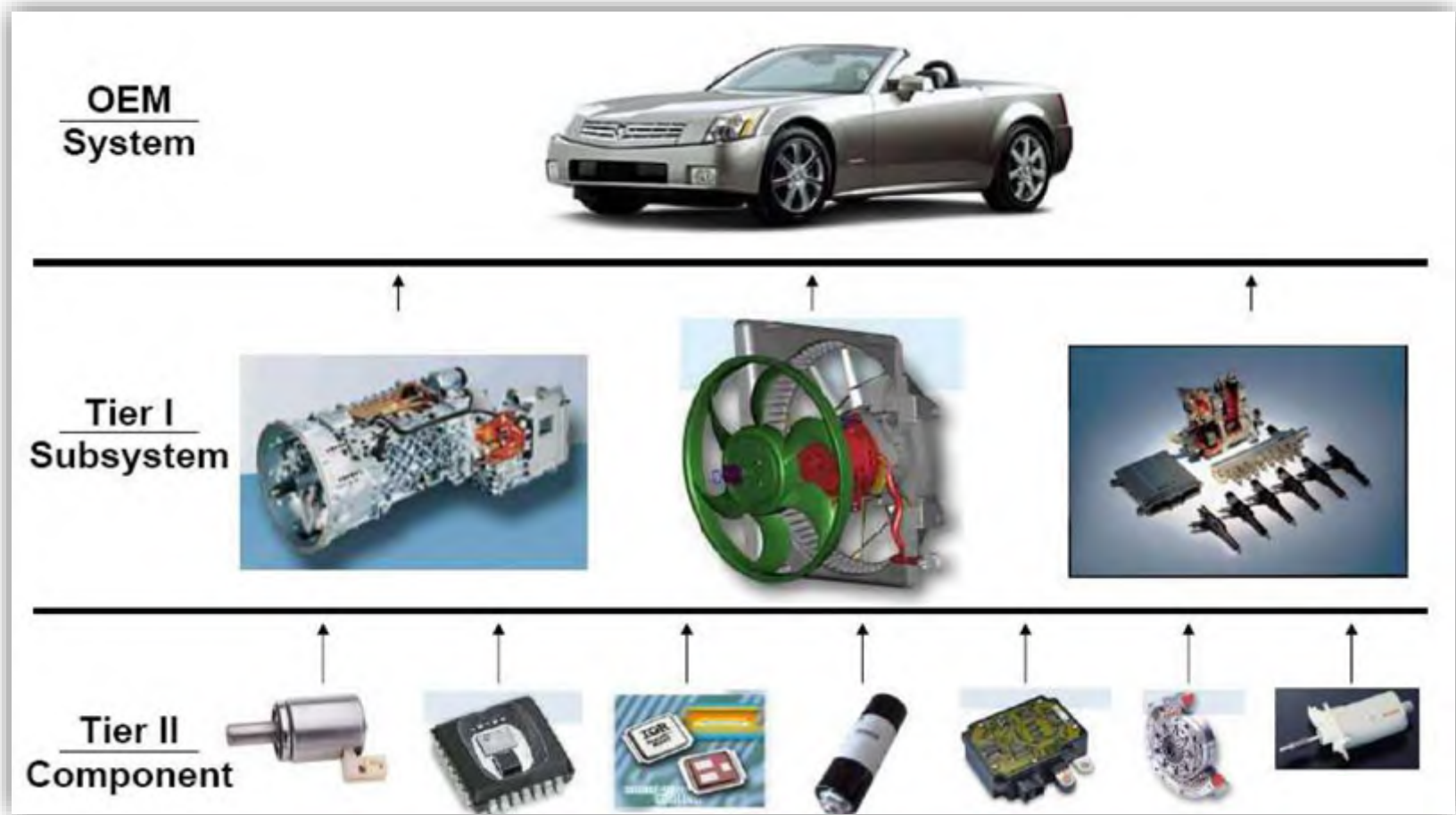


复杂系统载体

电磁兼容频段复杂

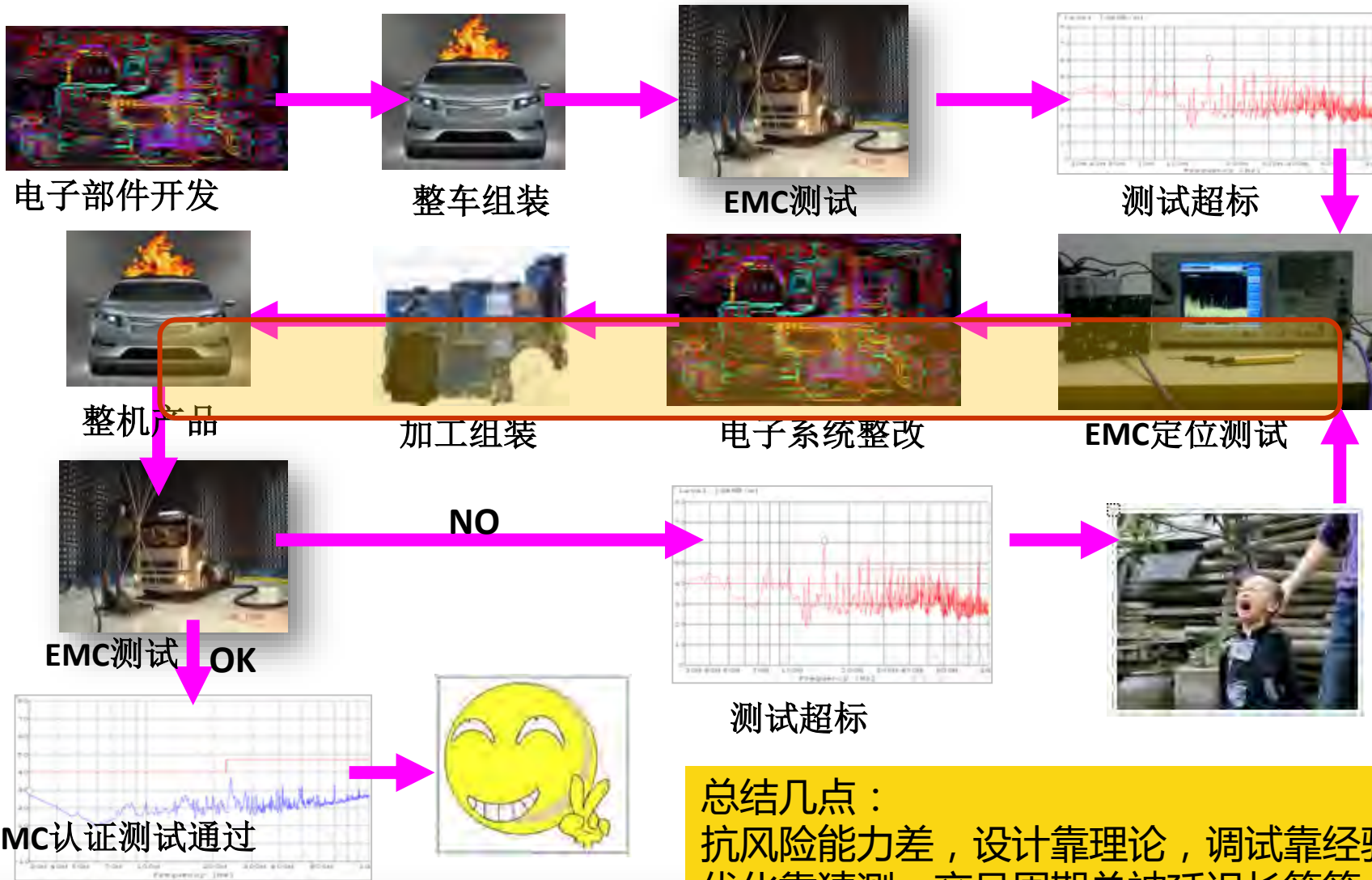


电磁兼容设计是一项复杂的系统工程



ISO/IEC 15288:2008: "A combination of interacting elements organized to achieve one or more stated purposes."

传统电子设计流程无法满足电磁兼容的设计要求



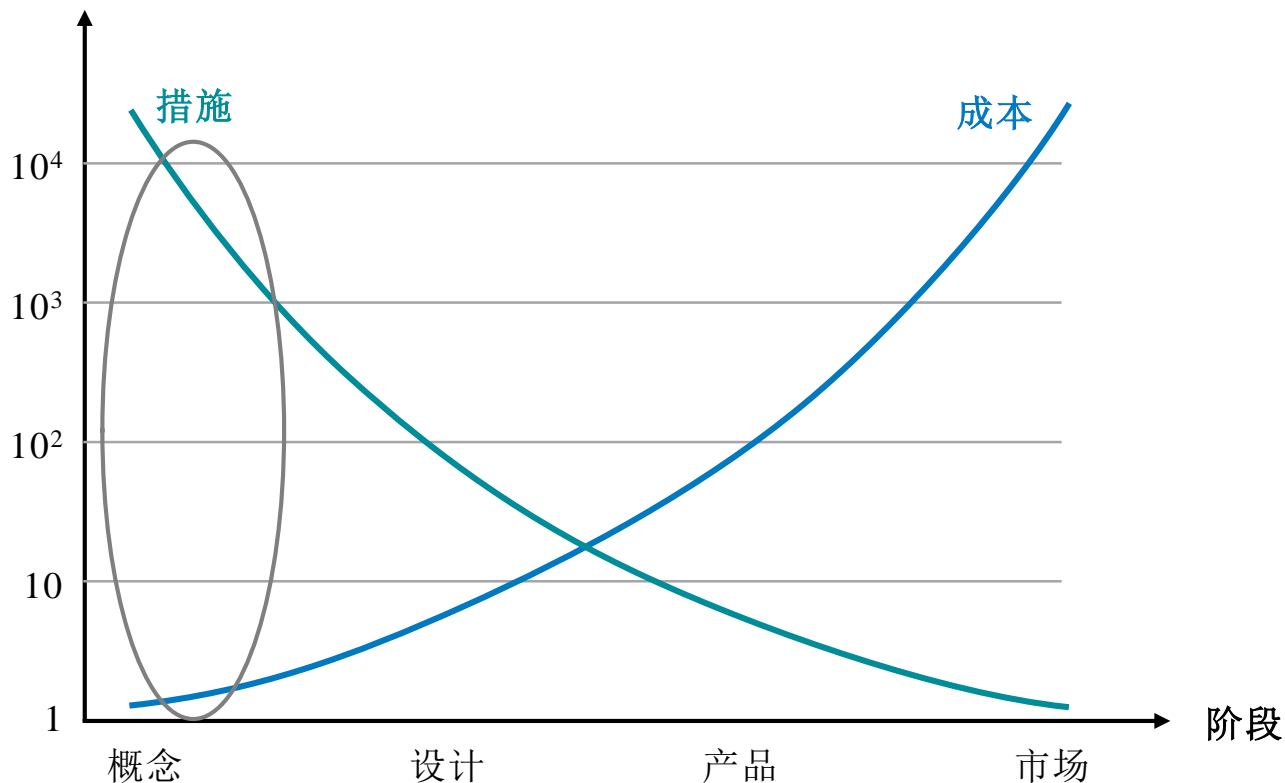
总结几点：
抗风险能力差，设计靠理论，调试靠经验，
优化靠猜测，产品周期总被延迟长等等。

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- ANSYS EMC仿真平台及能力介绍

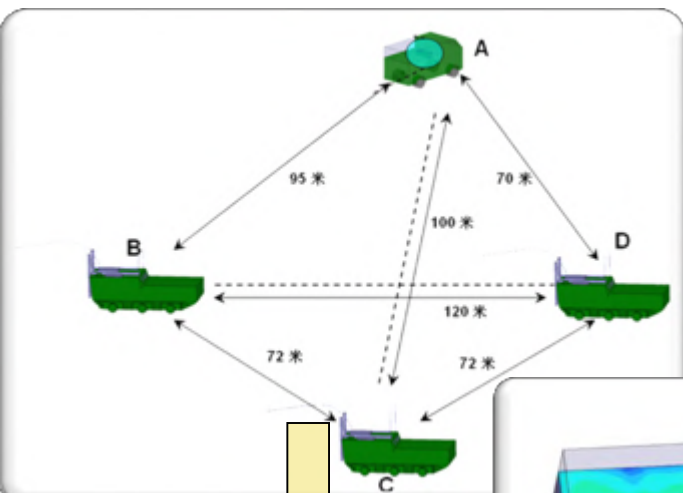
尽早解决电磁兼容问题十分必要

解决电磁兼容措施、成本与产品的开发过程的关系



- 解决电磁兼容问题的成本随着开发过程的呈指数级增长
- 越早发现电磁兼容问题，解决方法就越多
- 若后期才发现问题，解决的措施就大大减少，难度也会大很多
- **基于虚拟原型的仿真，是在早期发现电磁兼容问题、研究解决措施的最佳手段**

电磁兼容预测与分析的对象和目的

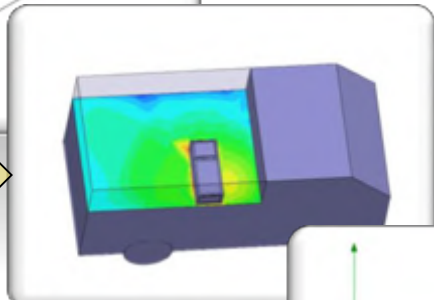
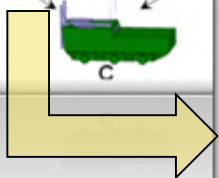


系统级

车辆、飞机、舰船

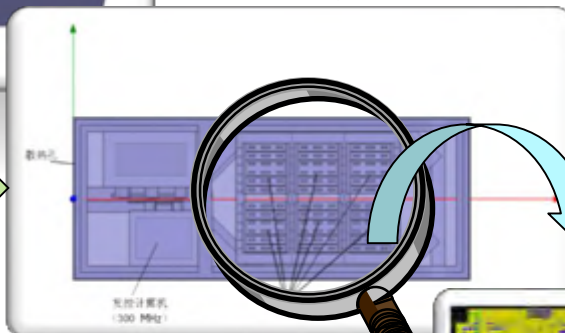
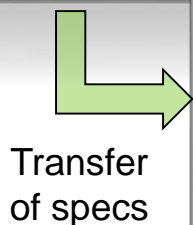
分析目的：

- ✓ 预测分析对象的电磁兼容性；
- ✓ 整改设计；
- ✓ 指标论证；
- ✓ 指标分配。



设备级

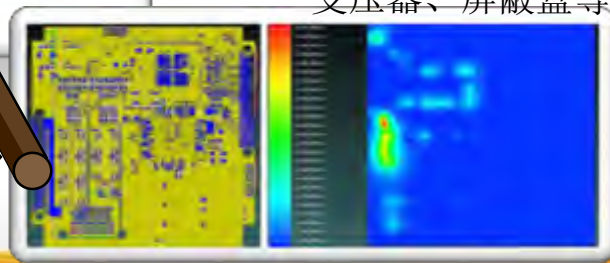
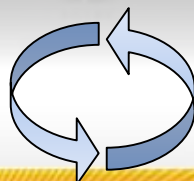
收发机、计算机、开关电源等电子设备



器件级

数模混合/高速/射频发射PCB、变压器、屏蔽盒等

验证/
改进设计



EMI/EMC 仿真分析需要何种软件？

EMI/EMC 分析软件

电路仿真

适用于功率电子、电路、控制系统仿真分析

优势：速度快、适合电路/系统级仿真分析
劣势：缺少物理原型系统仿真与集成能力

电磁场仿真

适用于二维/三维实体模型电磁特性分析

优势：精度高、适合精确计算对象特定电磁特性
劣势：缺少与电路/系统集成仿真分析能力

ANSYS

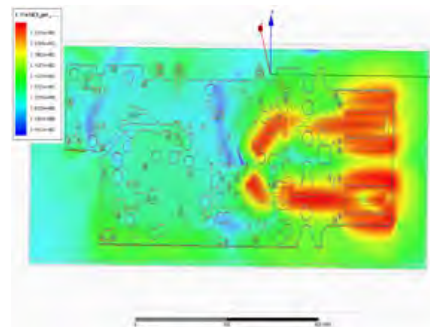
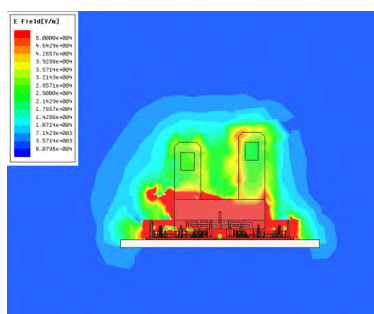
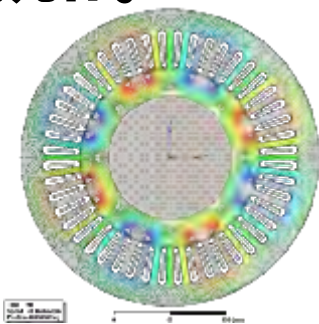
- 滤波
- 接地
- 传导
-

- 泄漏
- 屏蔽
- 辐射
-

电磁兼容仿真设计挑战

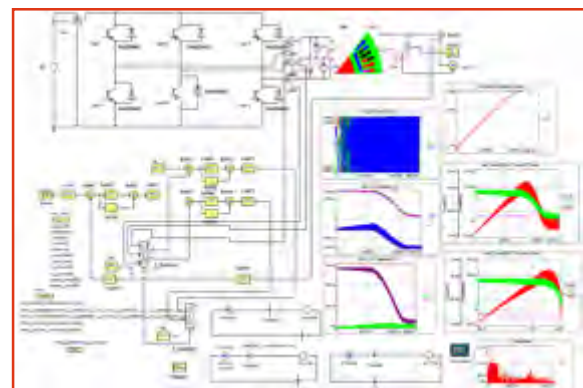
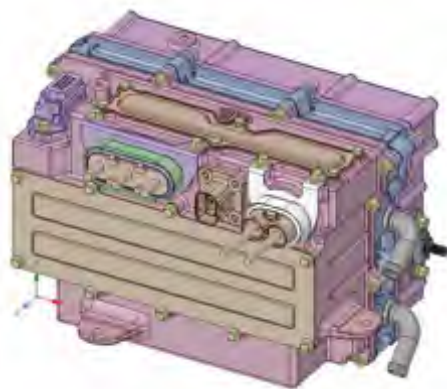
部件级

- 电源、电机、变流器、WPT
- 电子控制单元 (ECU)
- 天线、GPS、线缆



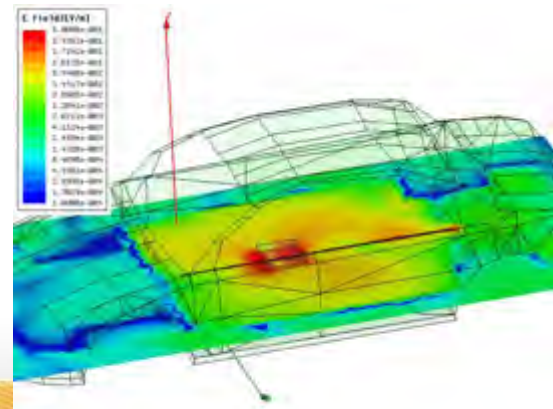
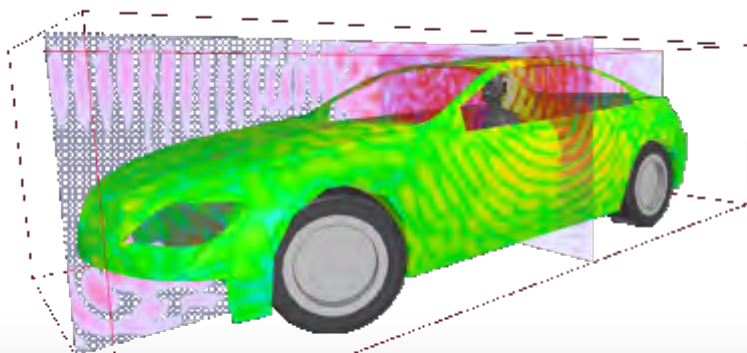
设备级/子系统级

- 各设备的辐射、抗干扰、ESD
- 功率电子、驱动控制子系统



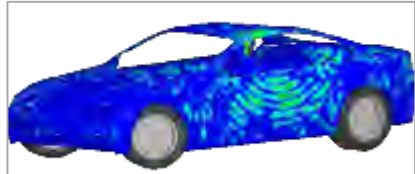
系统级

- 设备间电磁干扰
- 整车电气布局
- 整车辐射与屏蔽

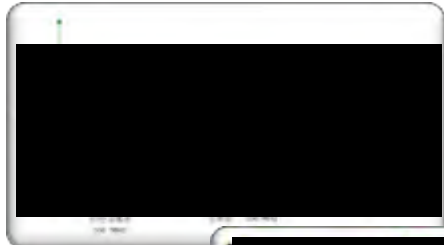


全系统仿真面临的主要困难——数据不全

系统级



设备级



部件级



全系统EMC仿真难点

- 电子部件多，工作频段容易重叠，产生干扰，数据获取困难
- 尺寸差距大，结构复杂
- 电路结构复杂，具备非线性效应
- 电磁应用环境复杂



- 分层次的EMC分析，基于已有数据进行分析
- 与量测结合，相互协同
- 专用工具与通用工具结合
- 场路协同，模拟系统真实工况
- 应用混合算法
- 使用HPC，提高求解效率

全系统电磁兼容仿真的三个层次

黑盒子

数据全面性：

- 不具备系统内的主要设备和部件数据；

仿真目的：

- 快速验证结论
- 研究设计规则

灰盒子

数据全面性：

- 具备系统内的部分数据，如关键线缆布局、设备机箱结构；

仿真目的：

- 关键部件的电磁兼容性分析；
- 系统具体电磁兼容性问题分析与定位；
- 研究设计规则

白盒子

数据全面性：

- 具备系统内的所有影响电性能的设备、部件和互连结构的数据；

仿真目的：

- 全面分析和预测系统电磁兼容性；
- 搭建系统电磁兼容性设计流程；
- 研究设计规则

* 针对不同的问题需要采用不同的仿真方法。

专用工具和通用工具结合

Discrete Components



Dimension < $\lambda/10$


Laminated Components/ boards



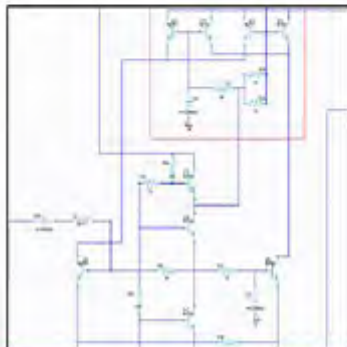
Device



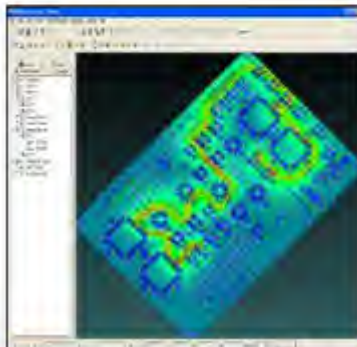
System



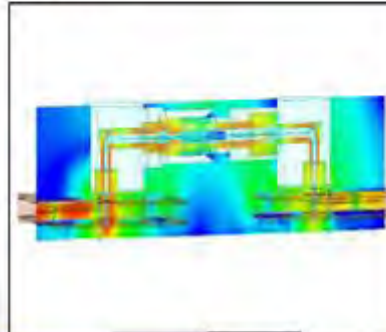
Circuit simulator



Hybrid EM fullwave solver (e.g SIWAVE)



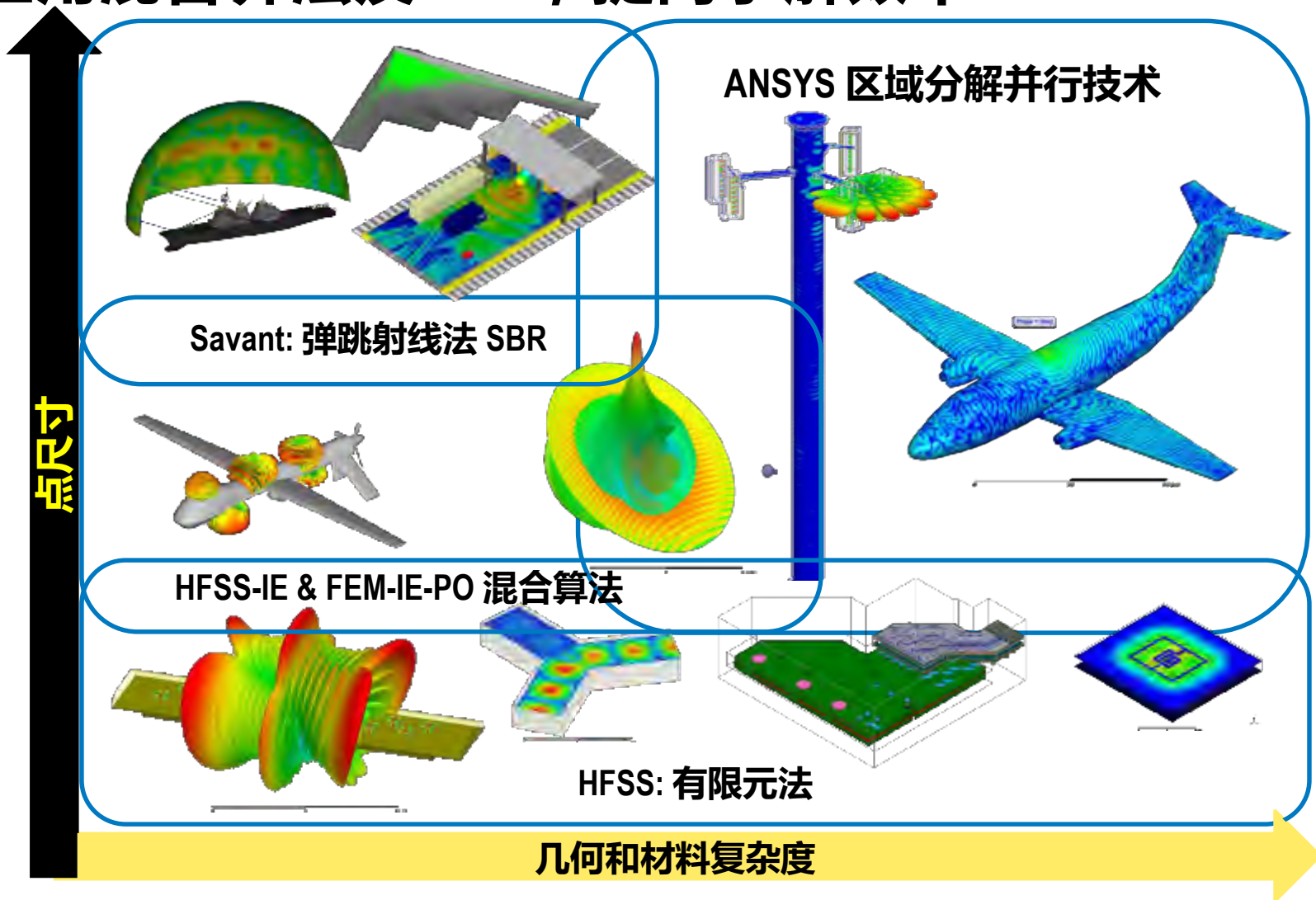
3D EM simulator, e.g HFSS



Fast simulator, e.g. Savant



应用混合算法及HPC，提高求解效率



与现有量测及设计手段的协同分析



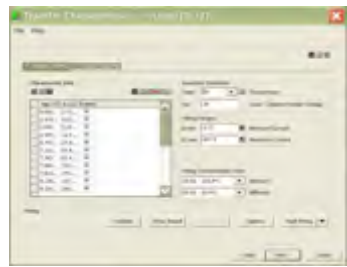
通过仿真平台的数据文件接口，可直接导入测试波形进行仿真。

开关器件特征化建模分析

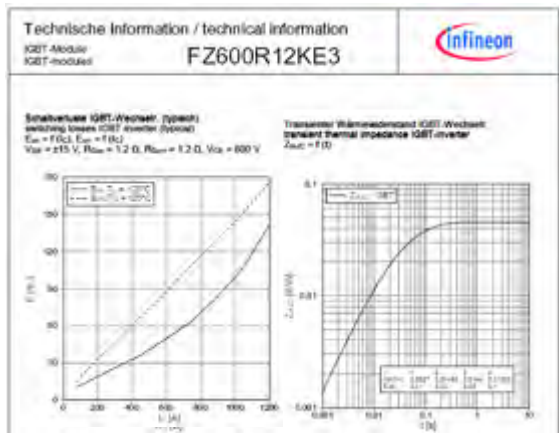


Infineon :
eupec FZ600R12KE3

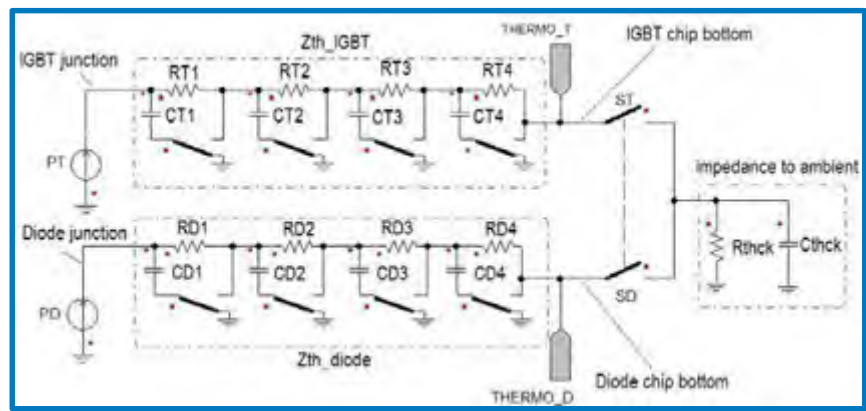
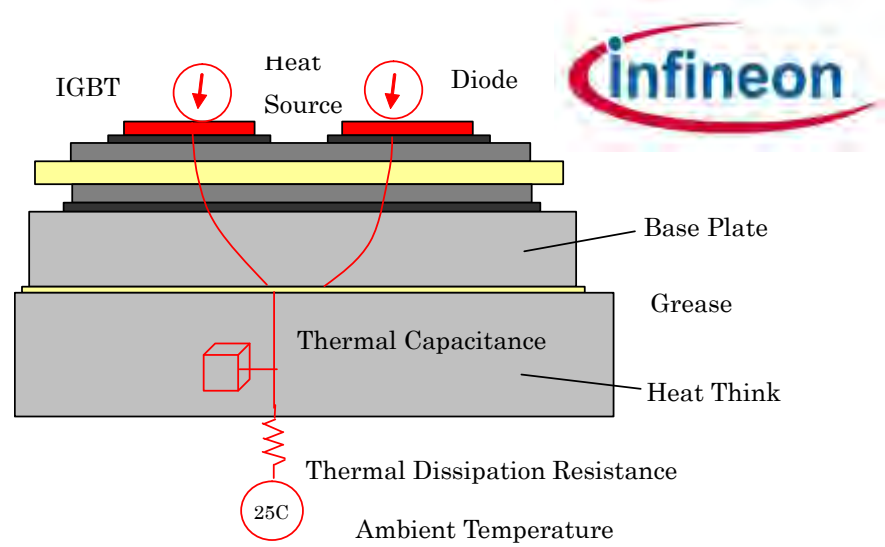
器件参数化建模
工具自动拟合由
参数提取工具提
取的数据



Extraction Tool



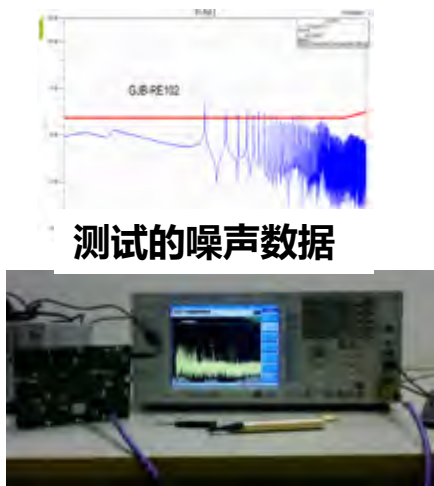
Data sheet



Thermal equivalent circuit
(IGBT & Diode built-in model)



场路协同/场场链接



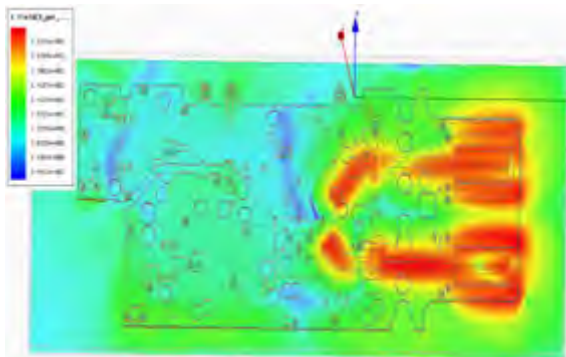
测试的噪声数据

Simplorer
 功率电子与电路系统分析

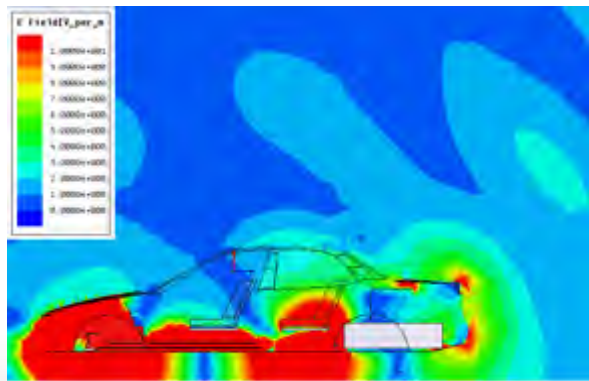
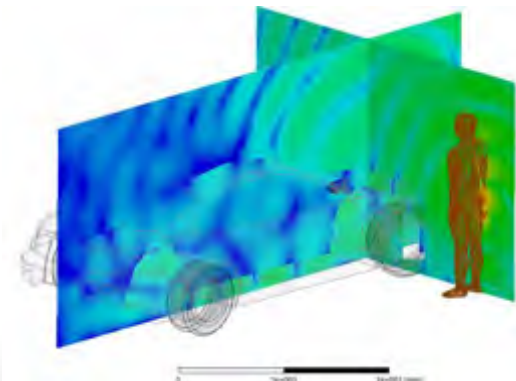
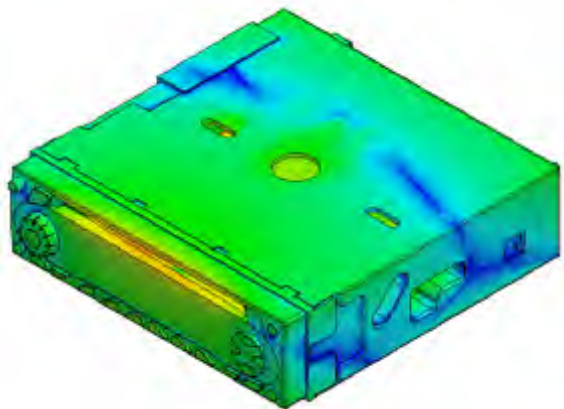


场路协同

HFSS
 三维机箱、车辆结构
 辐射仿真



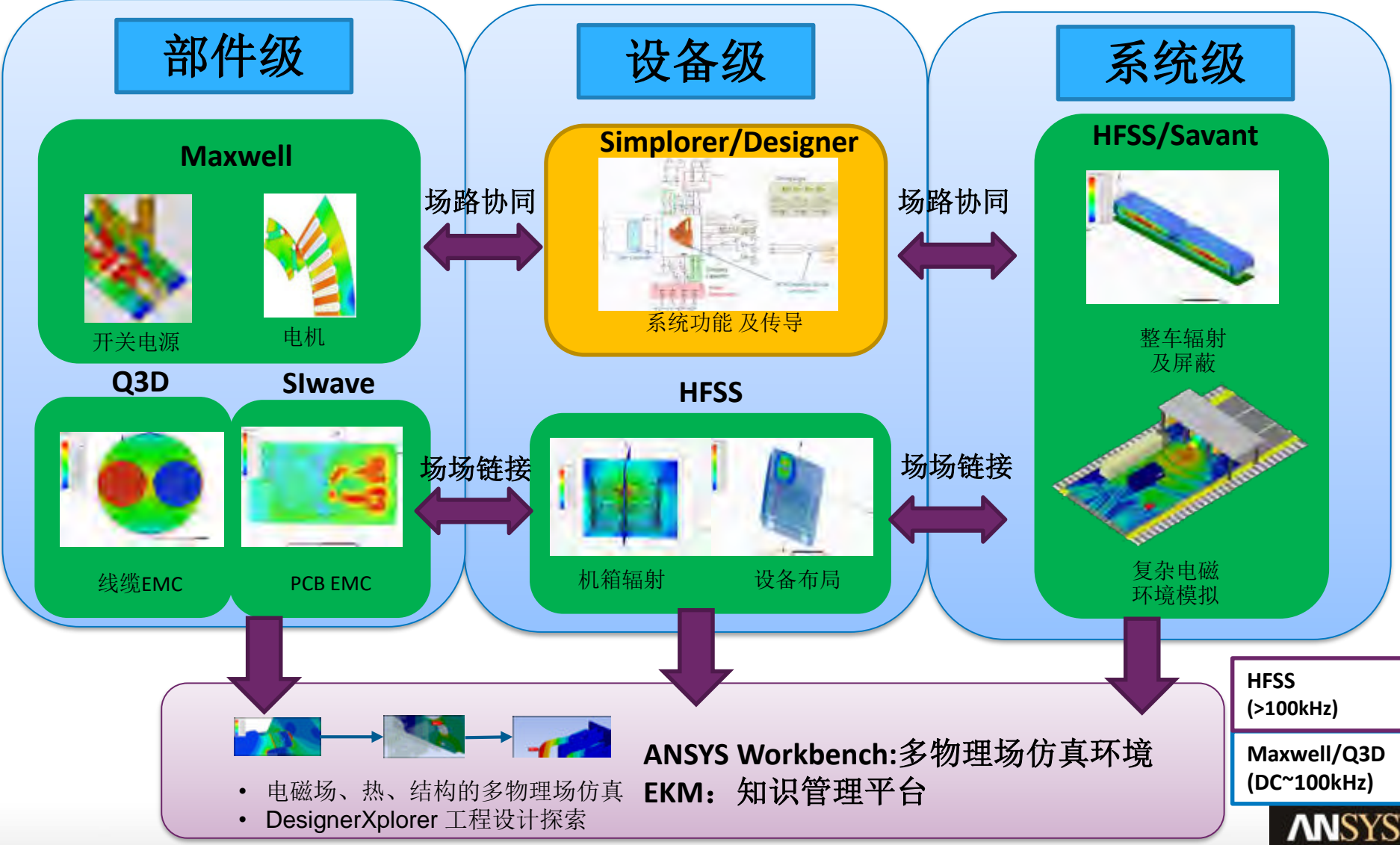
SIwave
 PCB近远场辐射仿真



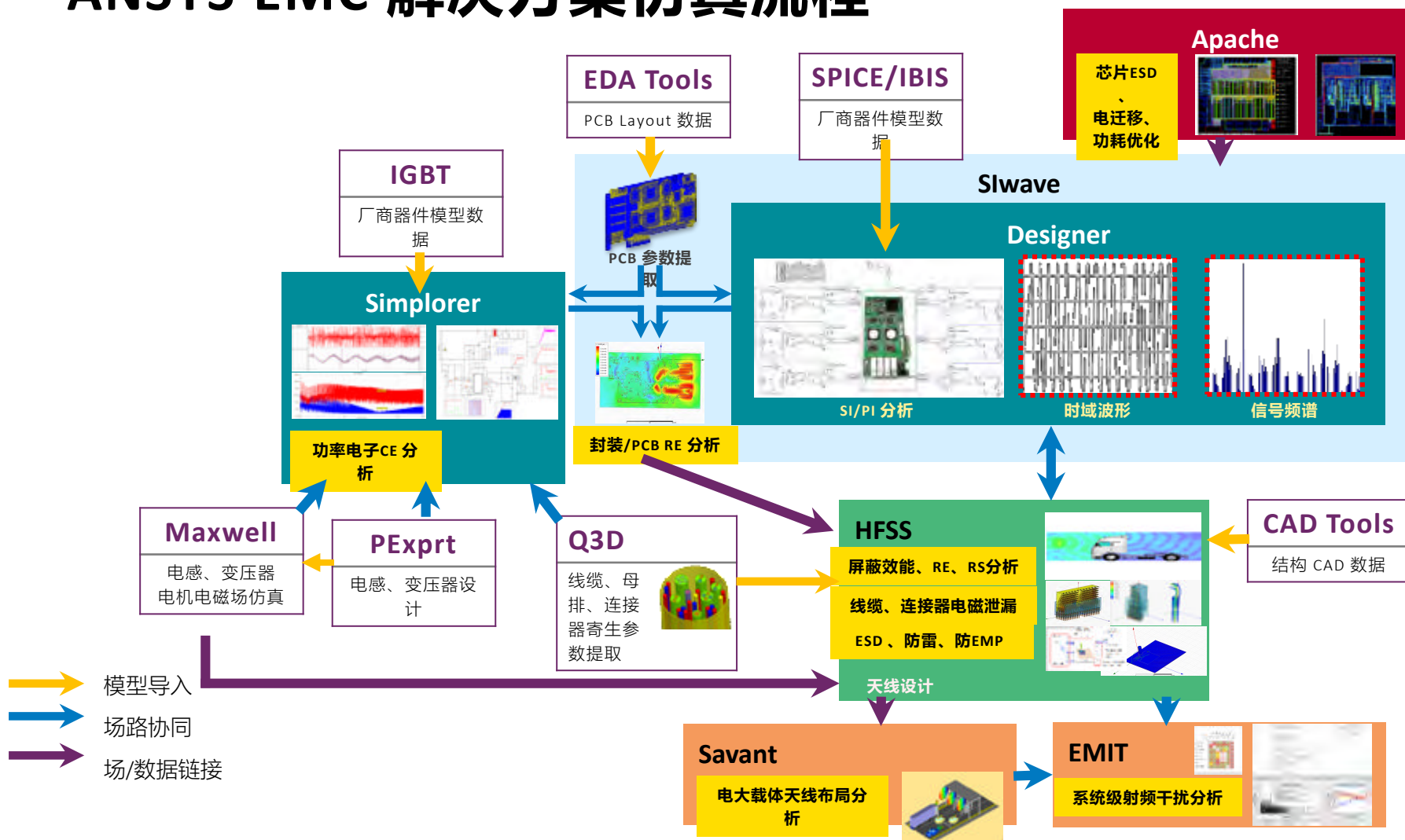
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- **ANSYS EMC仿真平台及能力介绍**

ANSYS EMC仿真平台



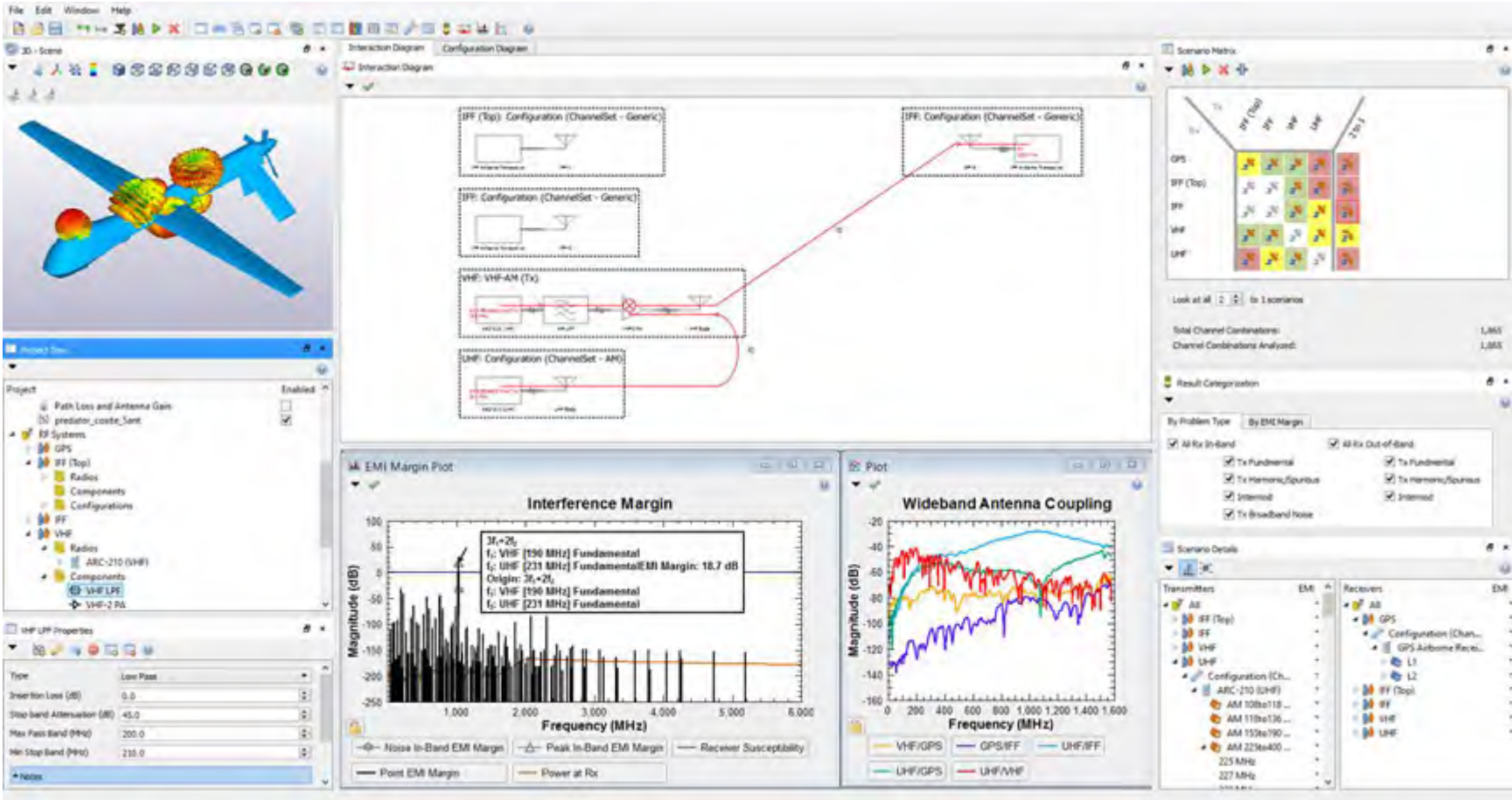
ANSYS EMC 解决方案仿真流程



ANSYS EMC分析能力

- **减少部件级辐射源头能量**
 - PCB SI/PI与EMI的相关仿真设计
 - 电感、滤波器器件选型及设计
- **控制部件间耦合路径干扰**
 - 耦合路径定位及电磁泄漏评估
- **加强设备级受害器件保护**
 - 设备布局优化
 - 设备屏蔽效能优化
- **虚拟EMC测试**
 - CE/RE/RS/BCI/HIRF/ESD

系统级EMC分析---EMIT



The screenshot displays the ANSYS EMIT software interface for system-level EMC analysis. The main window is divided into several panes:

- 3D Scene:** Shows a 3D model of an aircraft with various components highlighted in different colors (blue, yellow, red).
- Interaction Diagram:** A block diagram showing the configuration of various components and their interactions. Key components include:
 - IFF (Top) Configuration (ChannelSet - Generic)
 - IFF Configuration (ChannelSet - Generic)
 - VHF: VHF-AM (Tx)
 - UHF Configuration (ChannelSet - AM)
- Scenario Matrix:** A table showing the configuration of different scenarios. The matrix includes columns for components like GPS, IFF (Top), IFF, VHF, and UHF, and rows for different configurations.

	IFF (Top)	IFF	VHF	UHF
GPS	On	On	On	On
IFF (Top)	On	On	On	On
IFF	On	On	On	On
VHF	On	On	On	On
UHF	On	On	On	On
- EM Margin Plot:** A plot showing the Interference Margin. The y-axis is Magnitude (dB) from -250 to 100, and the x-axis is Frequency (MHz) from 0 to 6,000. A legend indicates:
 - Noise In-Band EM Margin
 - Peak In-Band EM Margin
 - Receiver Susceptibility
 - Point EM Margin
 - Power at Rx
- Wideband Antenna Coupling Plot:** A plot showing the Wideband Antenna Coupling. The y-axis is Magnitude (dB) from -160 to -20, and the x-axis is Frequency (MHz) from 0 to 1,600. The legend includes:
 - VHF/GPS
 - GPS/IFF
 - UHF/IFF
 - UHF/GPS
 - UHF/VHF
- Scenario Details:** A pane showing the configuration of transmitters and receivers.

Transmitters	EM	Receivers	EM
All	-	All	-
IFF (Top)	-	GPS	-
IFF	-	Configuration (Chan...	-
VHF	-	GPS Airborne Rece...	-
UHF	-	L1	-
Configuration (Ch...	7	L2	-
ARC-210 (UHF)	-	IFF (Top)	-
AM 108to118 ...	-	IFF	-
AM 118to136 ...	-	VHF	-
AM 155to190 ...	-	UHF	-
AM 225to400 ...	-		-
225 MHz	-		-
227 MHz	-		-
- Project Tree:** A hierarchical view of the project structure, including Path Loss and Antenna Gain, RF Systems, GPS, IFF (Top), Components, Configurations, IFF, VHF, Radios, and UHF LPE.
- VHF LPE Properties:** A pane showing properties for the VHF LPE component, such as Insertion Loss (dB) and Stop Band Attenuation (dB).

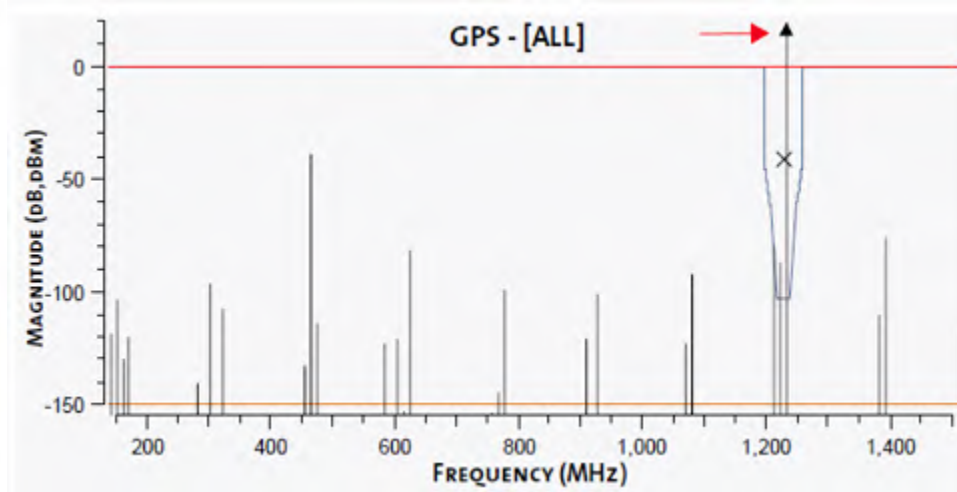
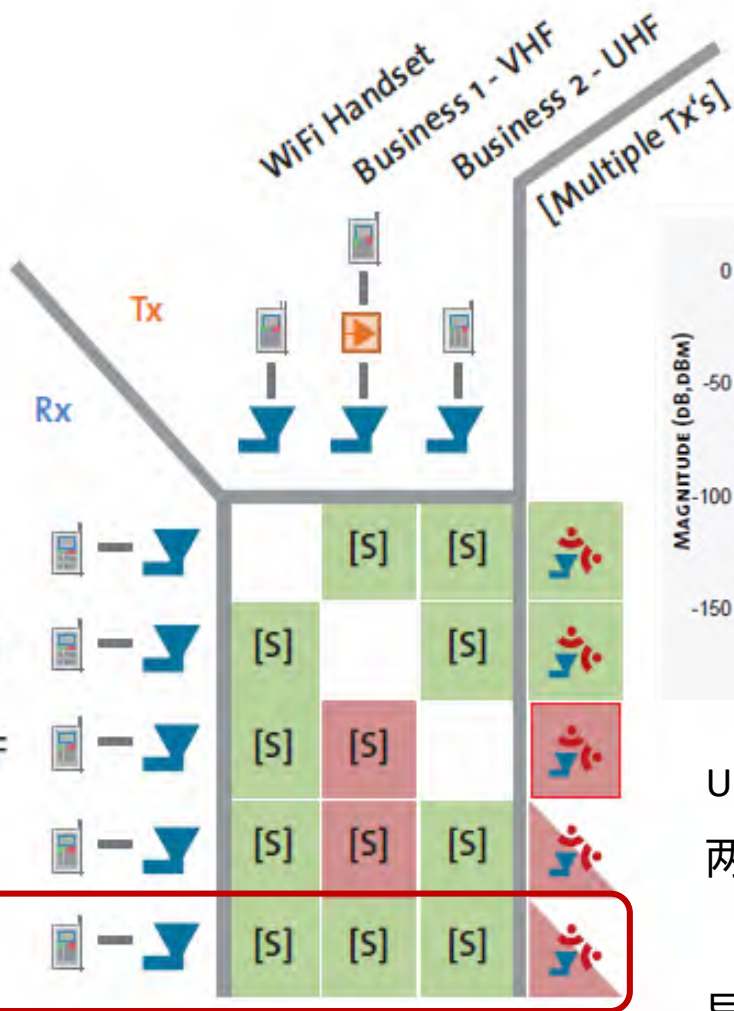
系统级EMC分析---EMIT

- **管理** 系统性能数据
- **仿真** RFI/EMI 效应
- **定位** RFI/EMI 的根本原因
- **解决** RFI/EMI 问题

The screenshot displays the ANSYS EMIT software interface. On the left, a 3D model of an aircraft is shown with various components highlighted in different colors. Below the model is a project tree with folders for 'RF Systems', 'GPS', 'IFF (Top)', 'Radios', 'Components', and 'Configurations'. The main workspace is divided into several panels:

- Interaction Diagram:** Shows a block diagram of the system's RF components, including 'IFF (Top)', 'IFF (Bottom)', 'VHF: VHF-AM (TX)', and 'UHF: Configuration (ChannelSet - AM)'. Red lines indicate signal paths between these components.
- EMI Margin Plot:** A graph titled 'Interference Margin' showing Magnitude (dB) vs. Frequency (MHz). It features a 'Noise In-Band EMI Margin' (black line) and a 'Peak In-Band EMI Margin' (red line). A callout box indicates: '3f=2f, f₁: VHF [190 MHz] Fundamental, f₂: UHF [231 MHz] Fundamental, EMI Margin: 16.7 dB, Origin: 3f=2f, f₁: VHF [190 MHz] Fundamental, f₂: UHF [231 MHz] Fundamental'.
- Wideband Antenna Coupling Plot:** A graph showing Magnitude (dB) vs. Frequency (MHz) for various antenna configurations: VHF/GPS, GPS/IFF, UHF/IFF, UHF/GPS, and UHF/VHF.
- Scenario Matrix:** A table on the right side of the interface showing the results of different channel combinations. It includes columns for 'Tx' (GPS, IFF (Top), IFF, VHF, UHF) and 'Rx' (IFF (Top), IFF, VHF, UHF). The matrix cells contain colored icons representing the results of each combination.
- Scenario Details:** A panel at the bottom right showing the configuration of transmitters and receivers for the selected scenario.

汽车上的多射频系统共址干扰仿真

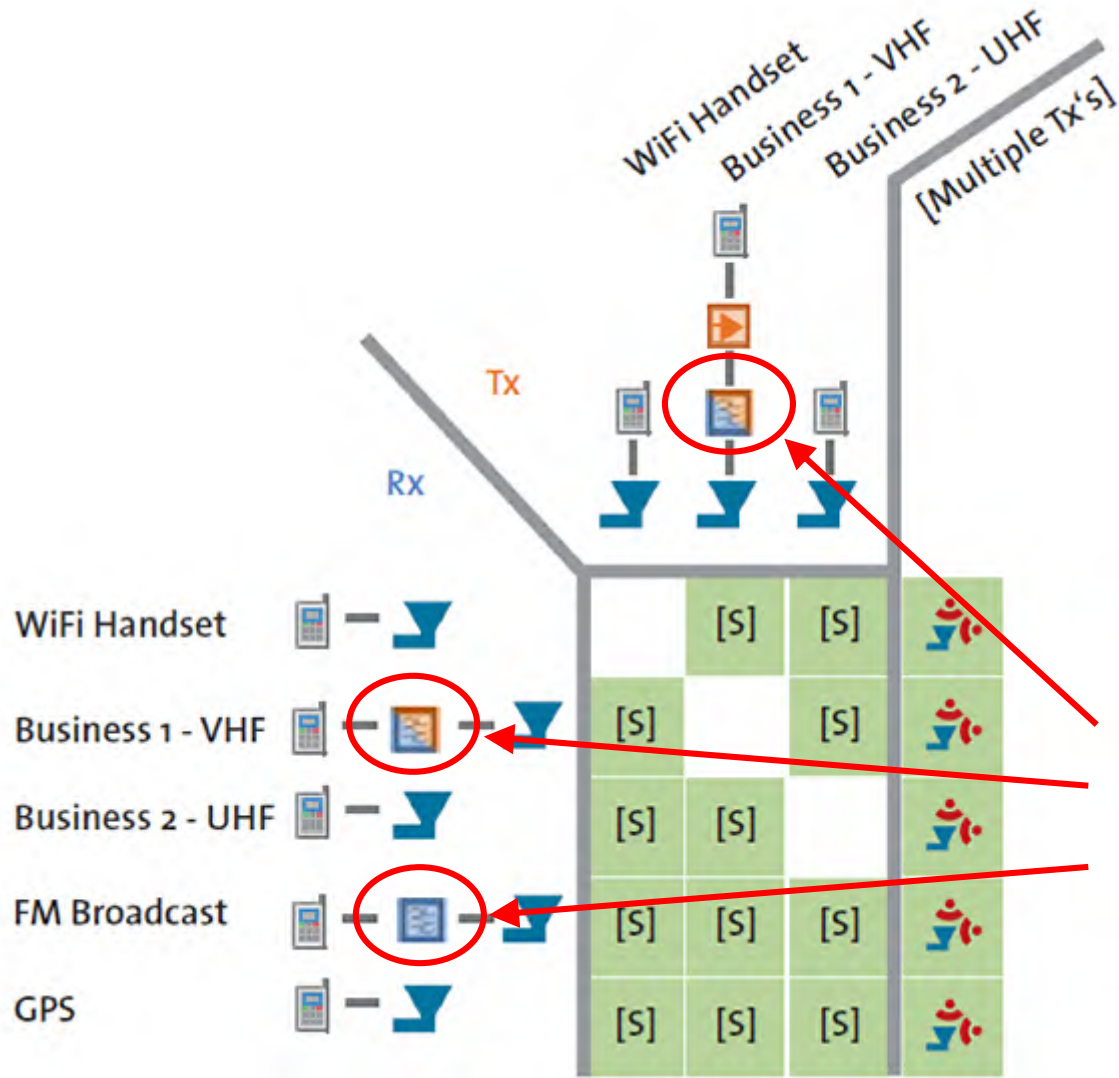


UHF的发射信号通过天线耦合至VHF发射通道，
两者在PA处产生的四阶交调产物：

$$(2 * 151.5\text{MHz} + 2 * 464.5\text{MHz} = 1232\text{MHz})$$

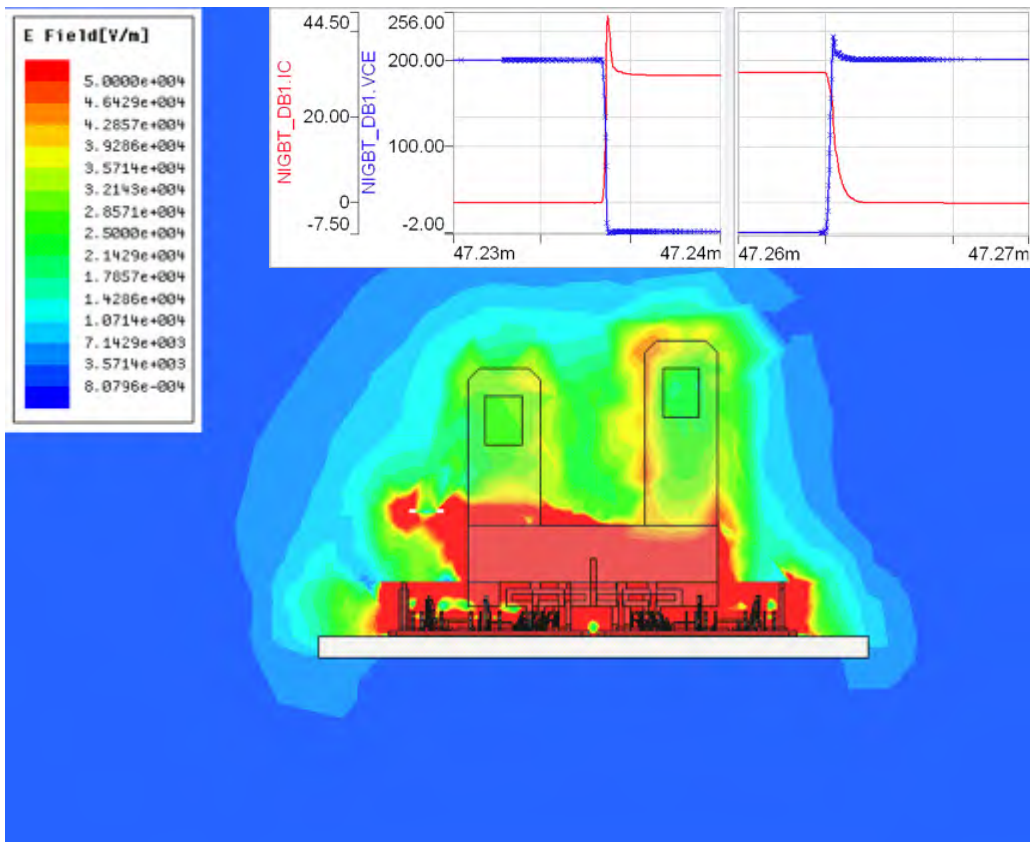
导致GPS灵敏度受扰

汽车上的多射频系统共址干扰仿真



在VHF和FM通道上使用
 带通滤波器
 帮助消除FM接收通道的
 干扰，以及VHF和UHF
 产生的交调产物影响
 GPS灵敏度

开关部件电磁辐射



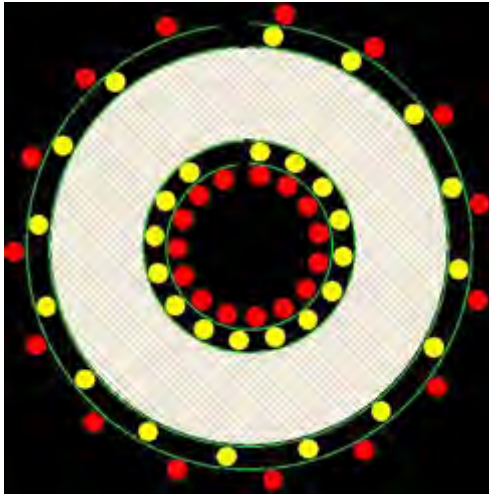
- 即使器件工作在110MHz，电场也主要分布在器件周围；
- 如果器件的功率非常高，可能造成距离器件很远的地方电场强度依然很高；
- 经过优化设计和分析，当前模型在110MHz工况下，工作情况良好。

Spectrum (MHz)	Power (W)	E field at 1m (V/m)
115.7024793	2308.359536	10.35553171

电场强度在110MHz，功率=10kW



变压器及滤波电感精确电磁设计

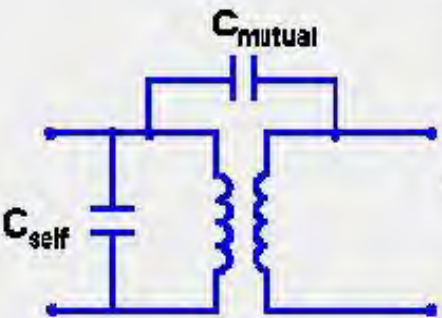


- 丰富的仿真结果和便捷的系统仿真模型提取（直流电阻、激磁电感、频变交流电阻和漏感、寄生/耦合电容、小信号测试等）

Ideal Short Circuit Values		Small Signal Test	Information
AC Resistance		Leakage Inductance	
DC Resistance and Lmag		Capacitive Effects	

Winding	DC Resistance (...)	Magnetizing Inductanc...
Winding A	19.8262	1013.25
Winding B	26.0914	1013.44

Ideal Short Circuit Values	Small Signal Test	Information
AC Resistance	Leakage Inductance	
DC Resistance and Lmag	Capacitive Effects	



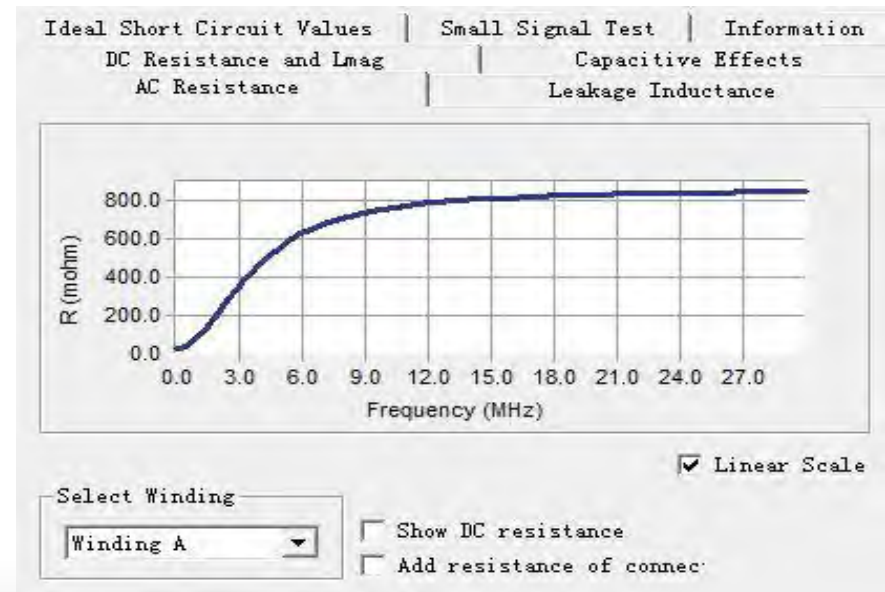
Self Capacitive Effects (pF)

1.73

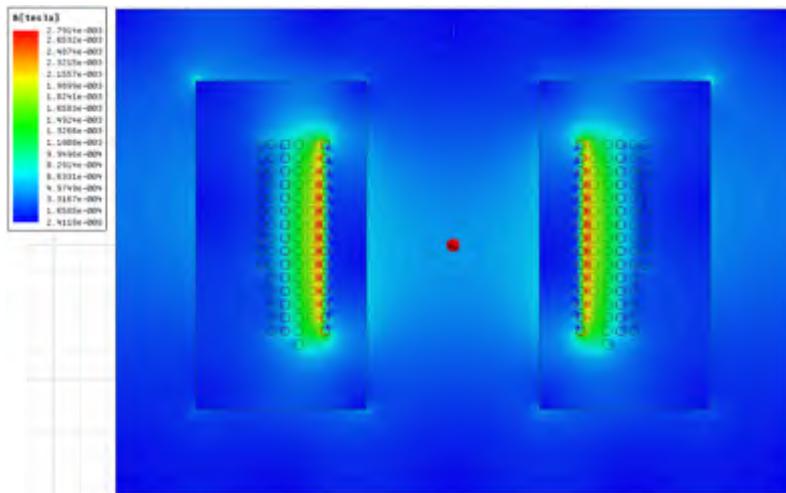
Mutual Capacitive Effects (pF)

Cap [A_B]

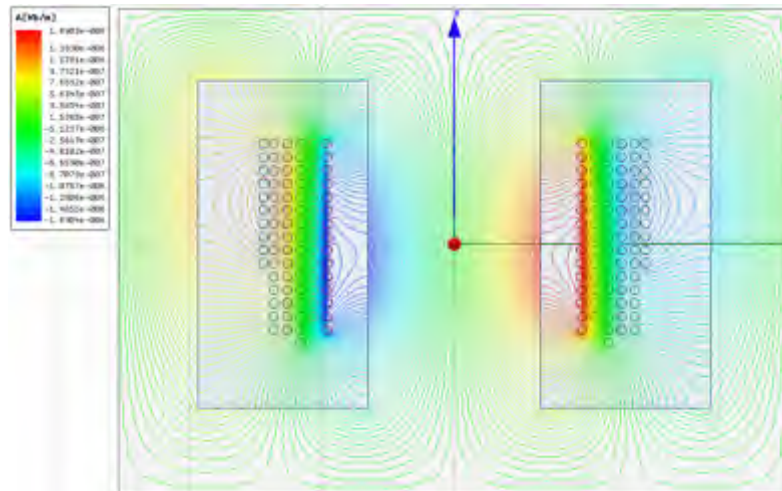
9.4



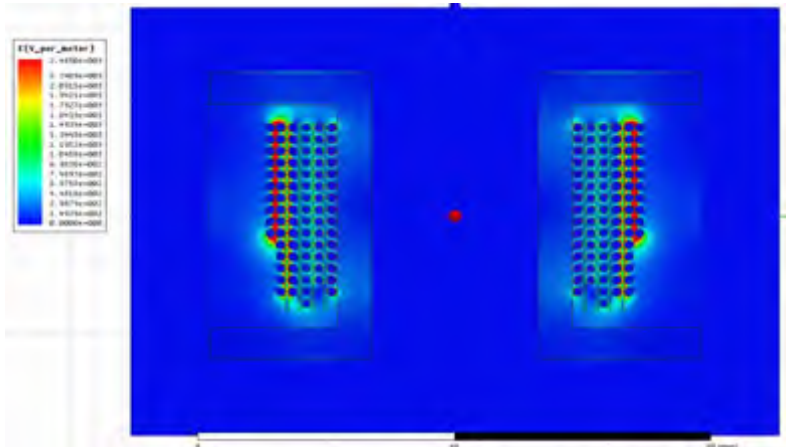
变压器及滤波电感精确电磁设计



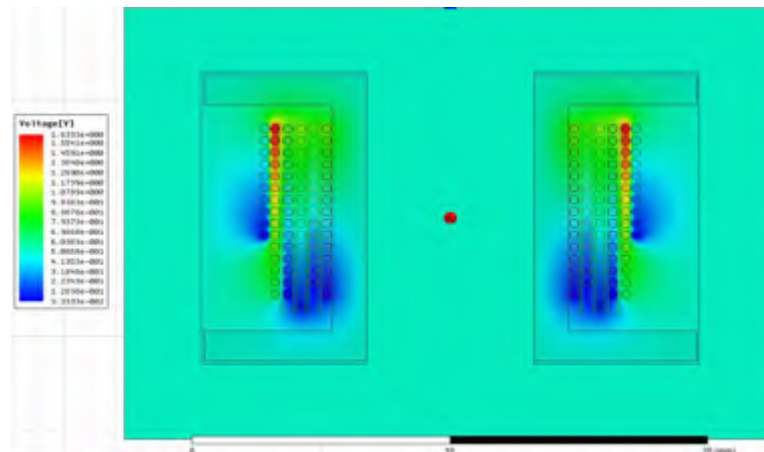
磁密分布



磁力线分布

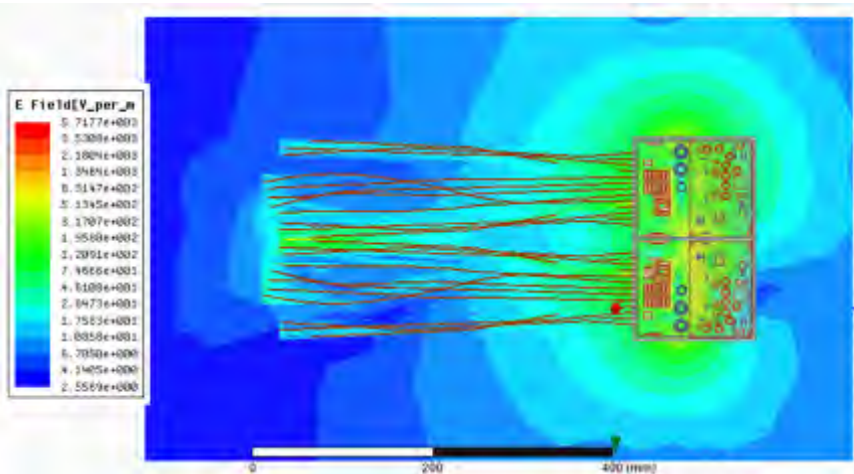


电场强度分布

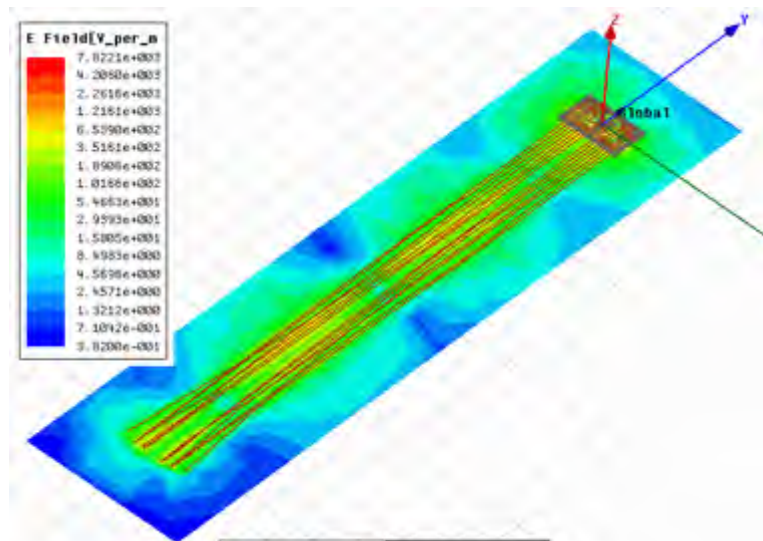


电位分布

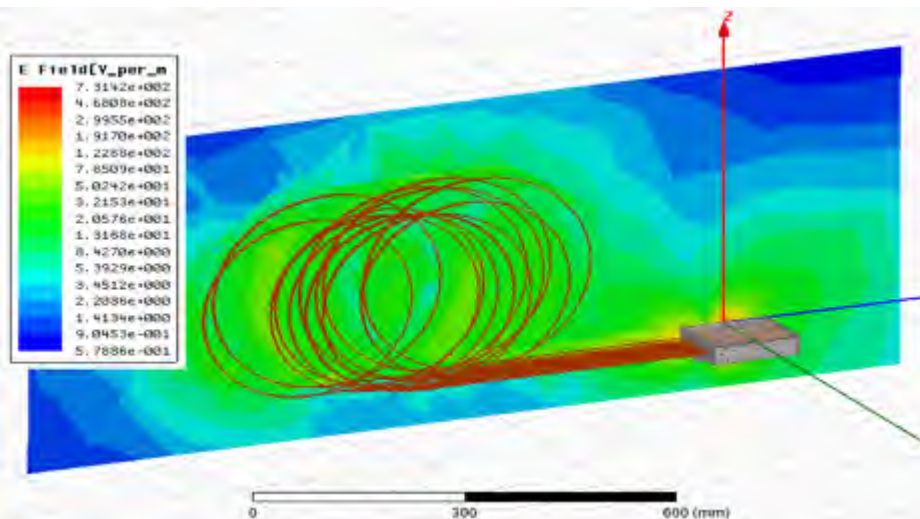
电缆辐射云图



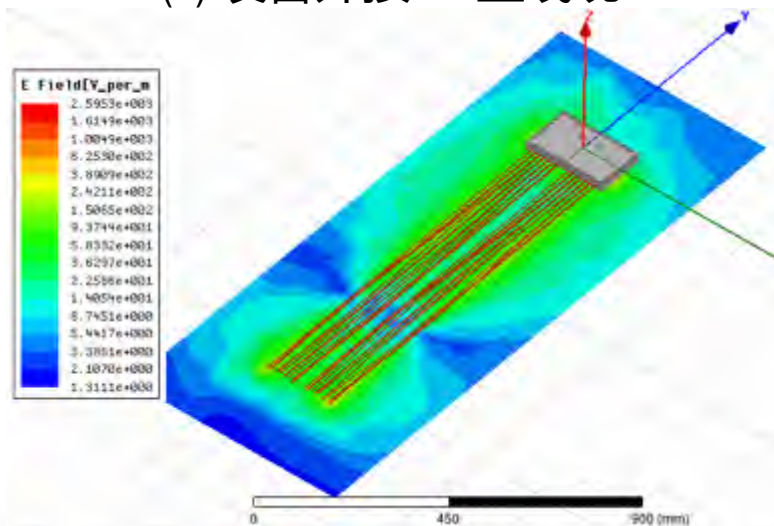
(1) 设备外接40cm 直线缆



(2) 设备外接2m 直线缆

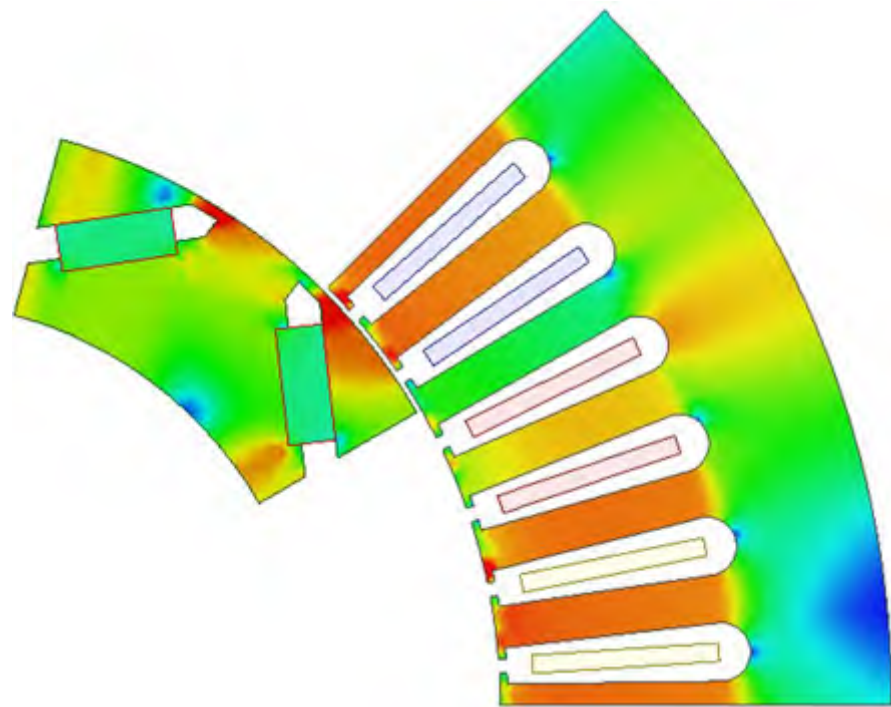


(3) 设备外接2m 卷曲线缆



(4) 设备外接1m 直线缆

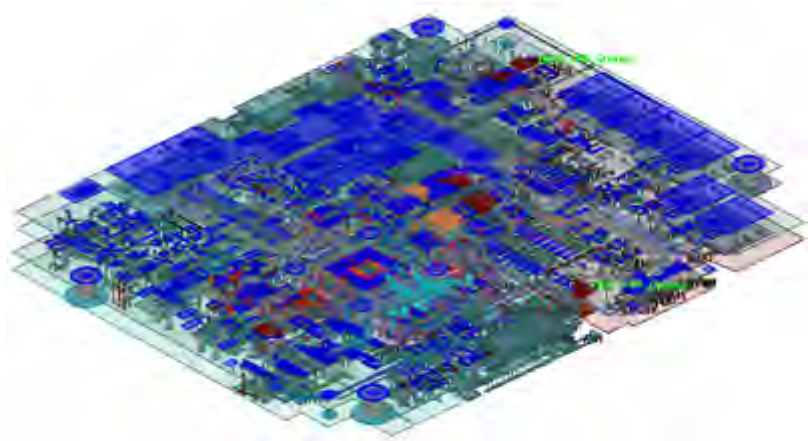
电机辐射云图



参考资料：

1. REPORT ON TOYOTA/PRIUS MOTOR TORQUE CAPABILITY, TORQUE PROPERTY, NO-LOAD BACK EMF, AND MECHANICAL LOSSES, J. S. Hsu, Ph.D. C. W. Ayers C. L. Coomer R. H. Wiles Oak Ridge National Laboratory S. L. Campbell K. T. Lowe R. T. Michelhaugh Oak Ridge Institute for Science and Education
2. Report on Toyota/Prius Motor Design and Manufacturing Assessment, J. S. Hsu, C. W. Ayers, C. L. Coomer, C. L. Coomer
3. Energy and Transportation Science Division Evaluation of 2004 Toyota Prius Hybrid Electric Drive System Interim Report T. A. Burrell S. L. Campbell C. L. Coomer C. W. Ayers A. A. Wereszczak J. P. Cunningham L. D. Marlino L. E. Seiber H. T. Lin

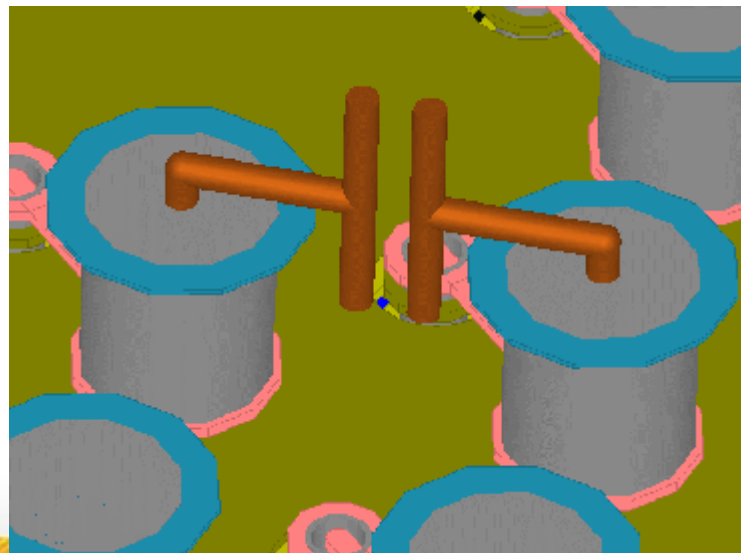
SIwave仿真PCB辐射



- 自带电容库(厂家测试的s参数)
- 通过厂家和器件编号进行选择
- 包含ESR, ESL
- 检查电容曲线和属性
- 根据焊盘尺寸准确建模器件焊接
- 快速为PCB器件赋值

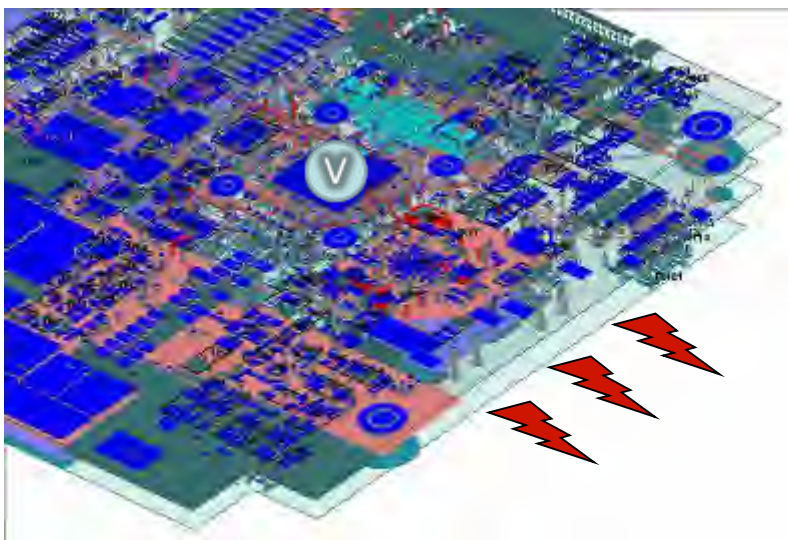
电源输入的PCB模型，加载真实器件模型

Siwave可提取PCB走线与真实器件的寄生参数后的电路传输曲线。



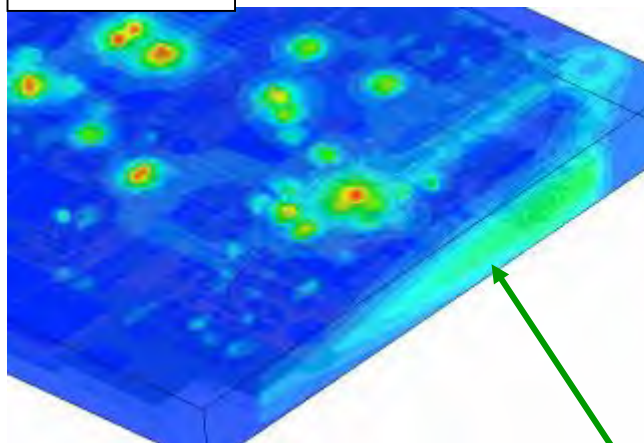
PCB辐射仿真分析---去耦电容优化

SIWAVE™



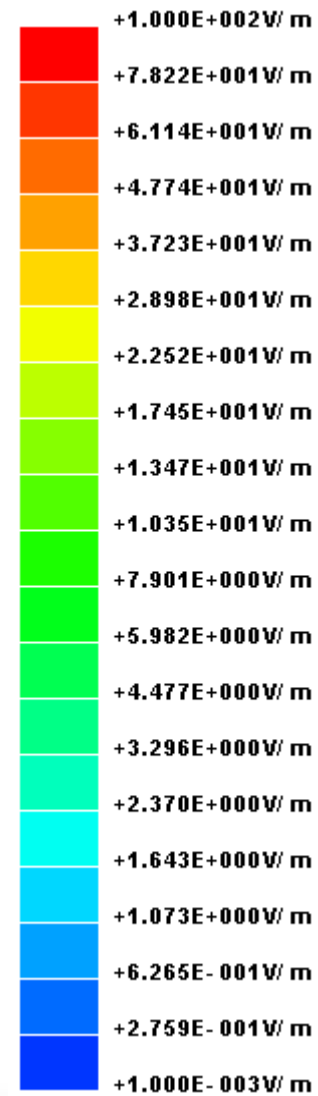
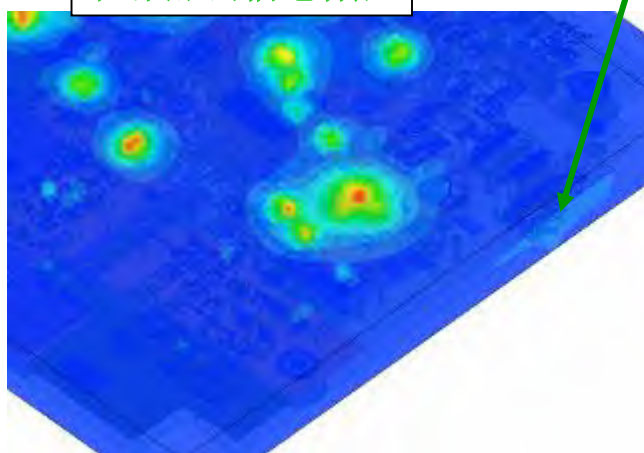
辐射从PCB板边逃逸，
由于1.17GHz频率处的谐振

去耦电容前

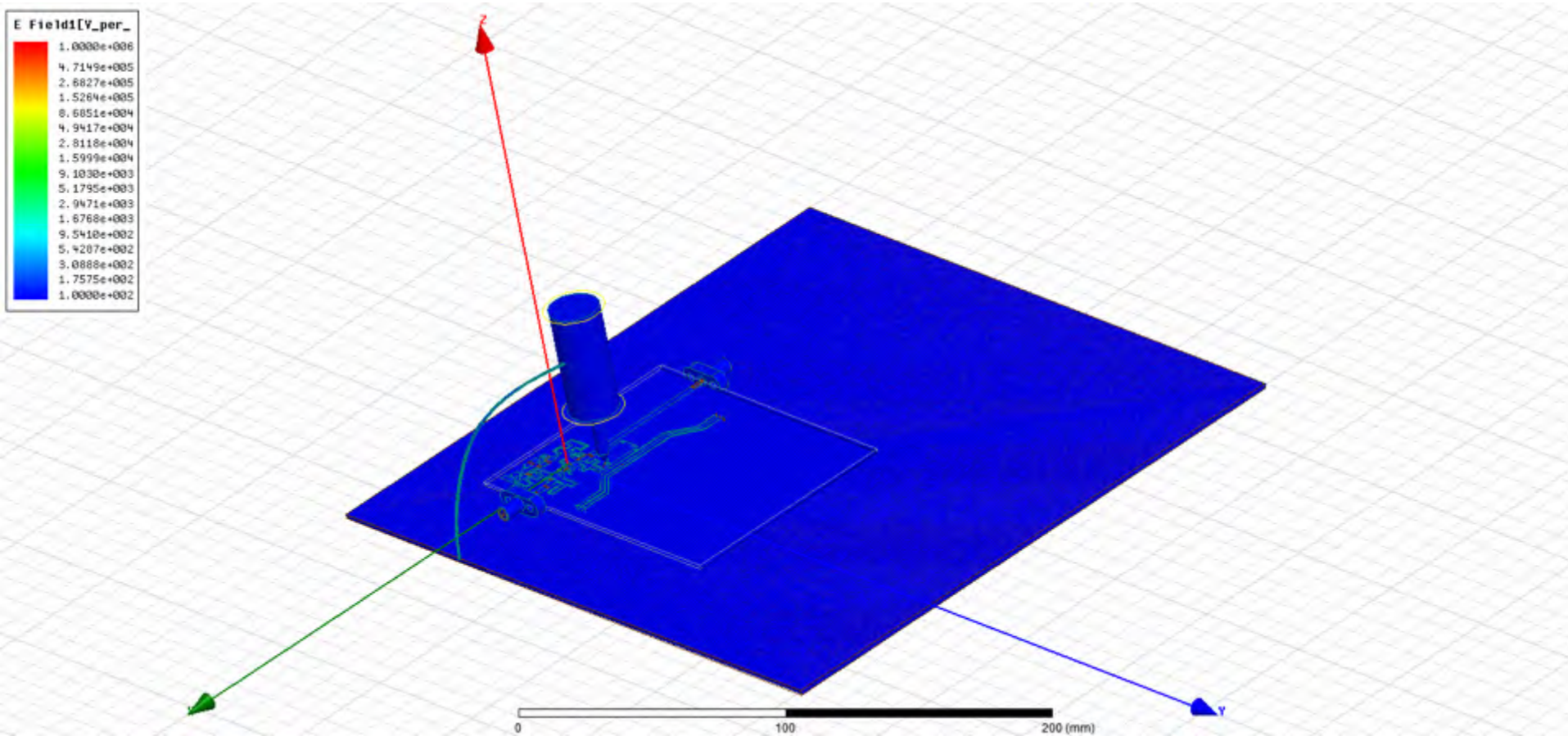


辐射减少了

在添加去耦电容后

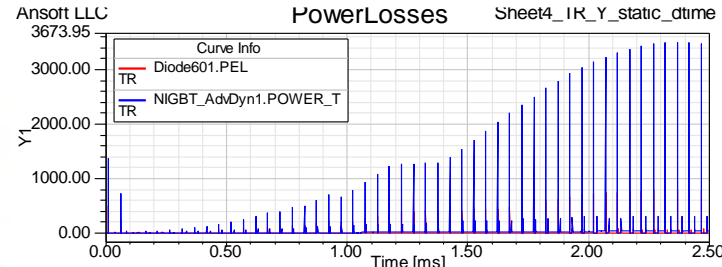
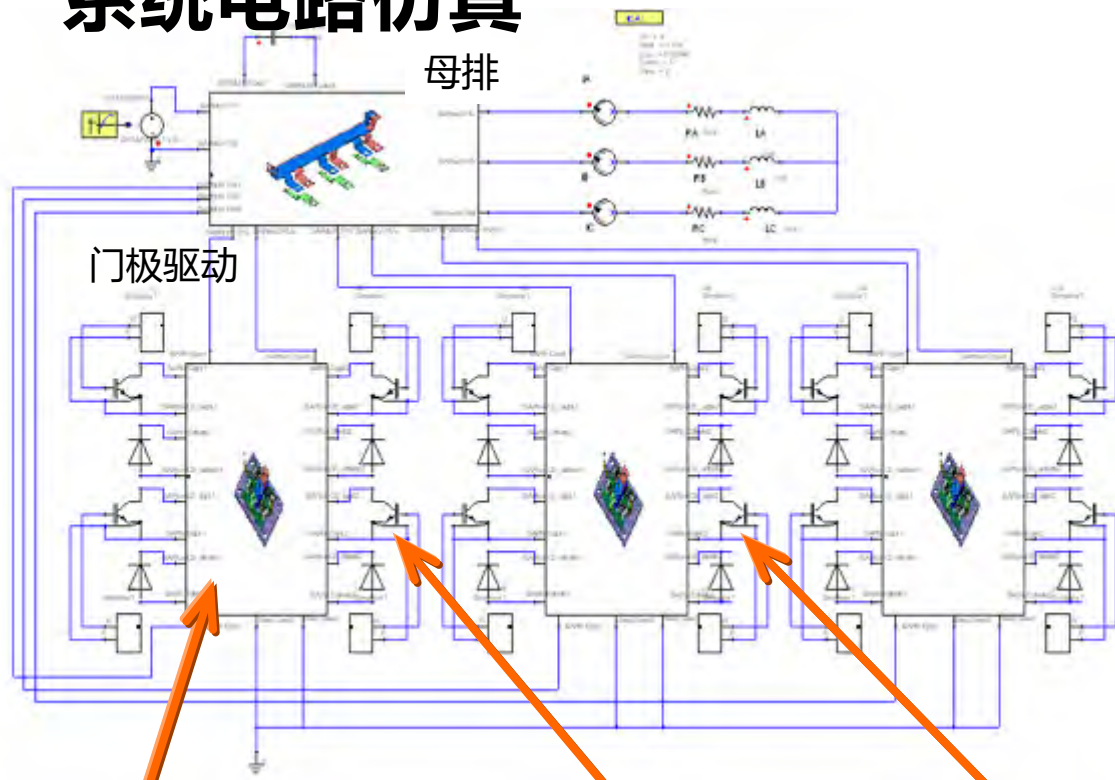


ESD瞬态仿真

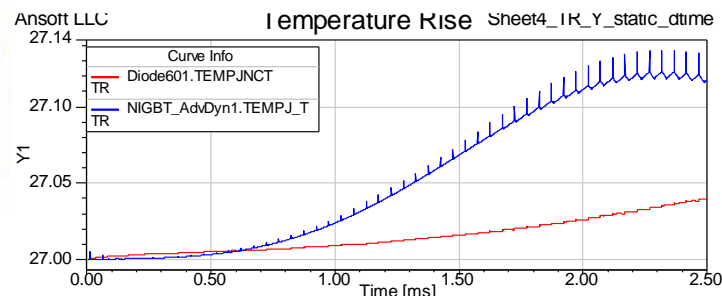


整个系统空间内电场的变化情况

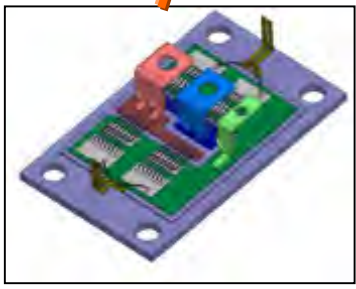
系统电路仿真



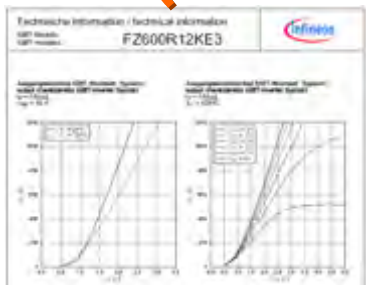
器件开关损耗波形



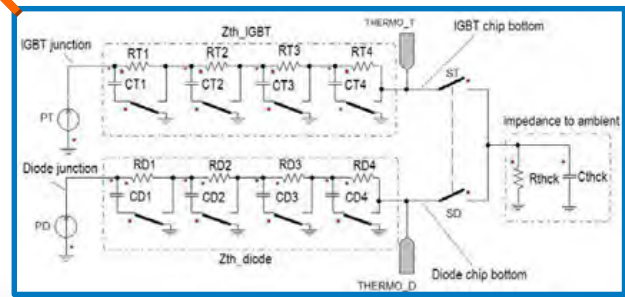
器件温升曲线



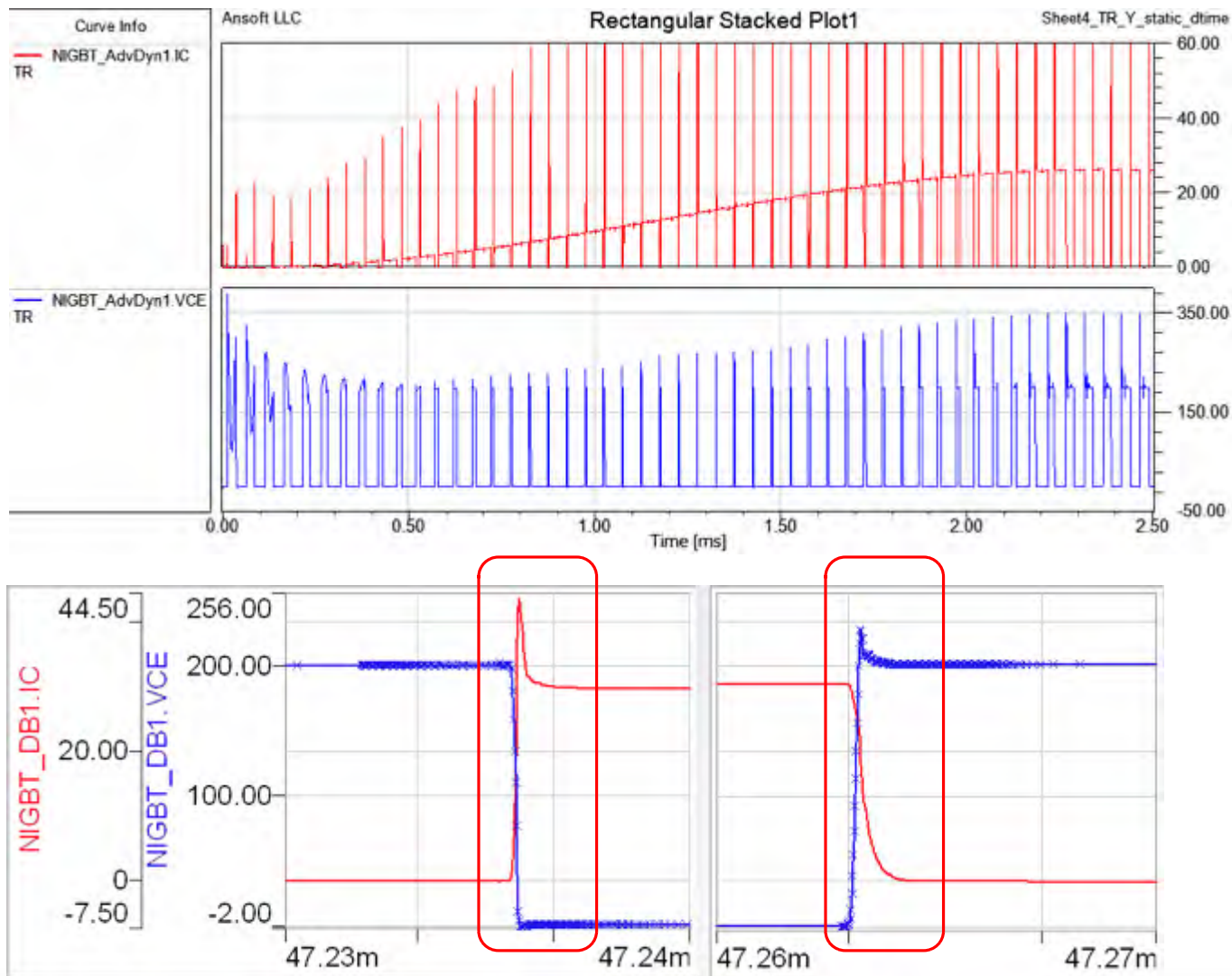
LCR参数矩阵



器件电气/热参数



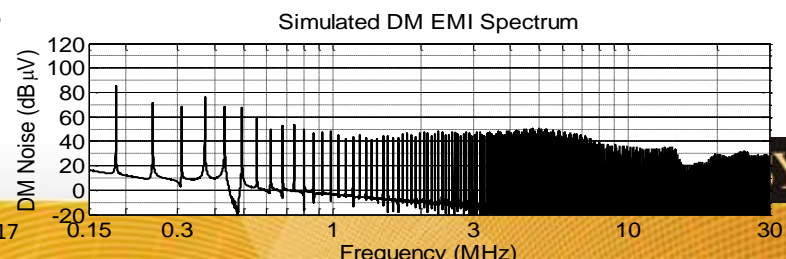
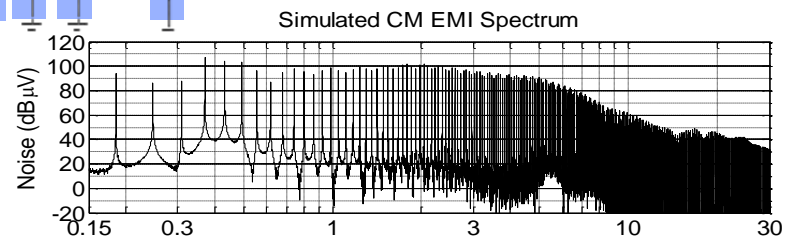
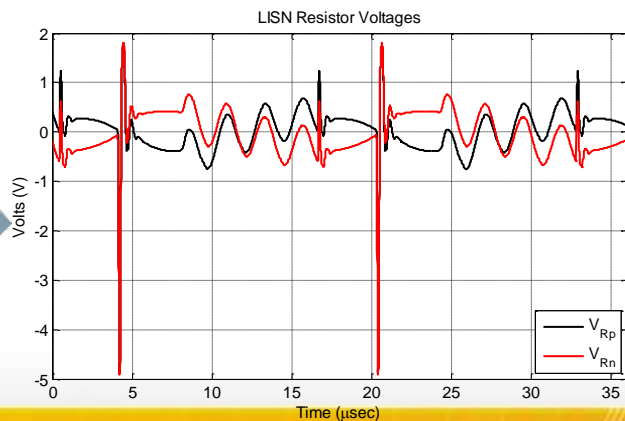
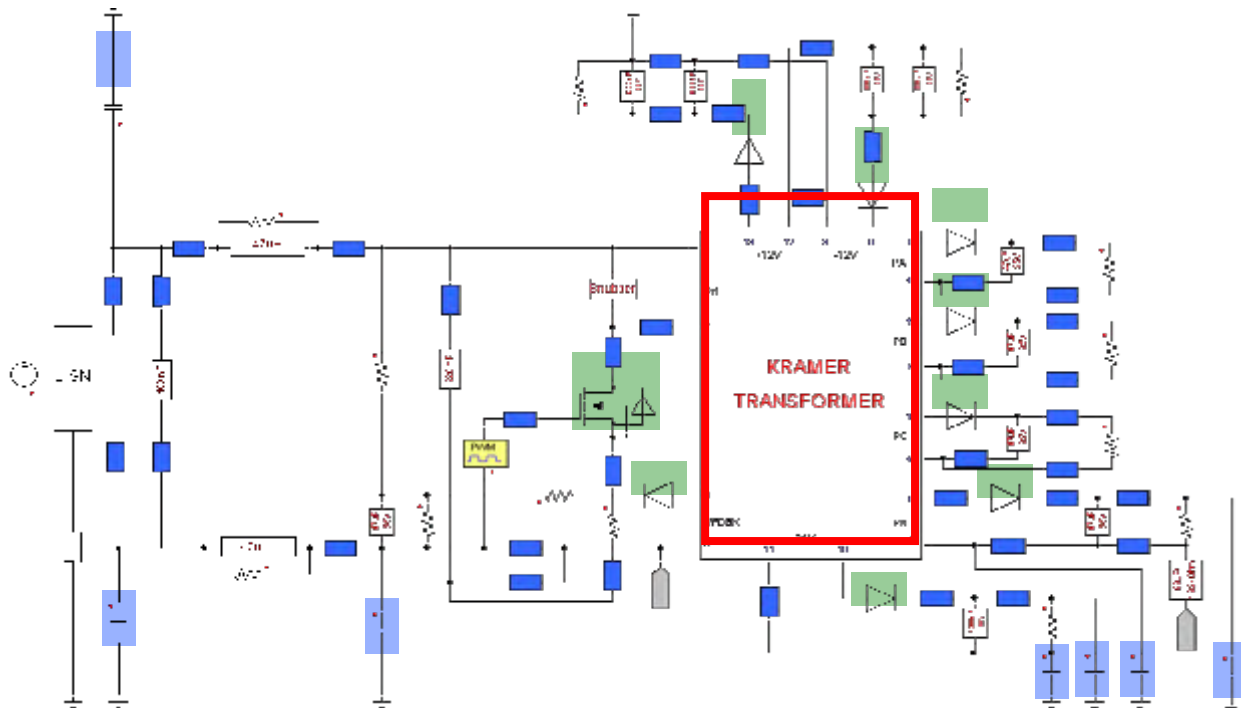
系统电路仿真：开关过程中的波形



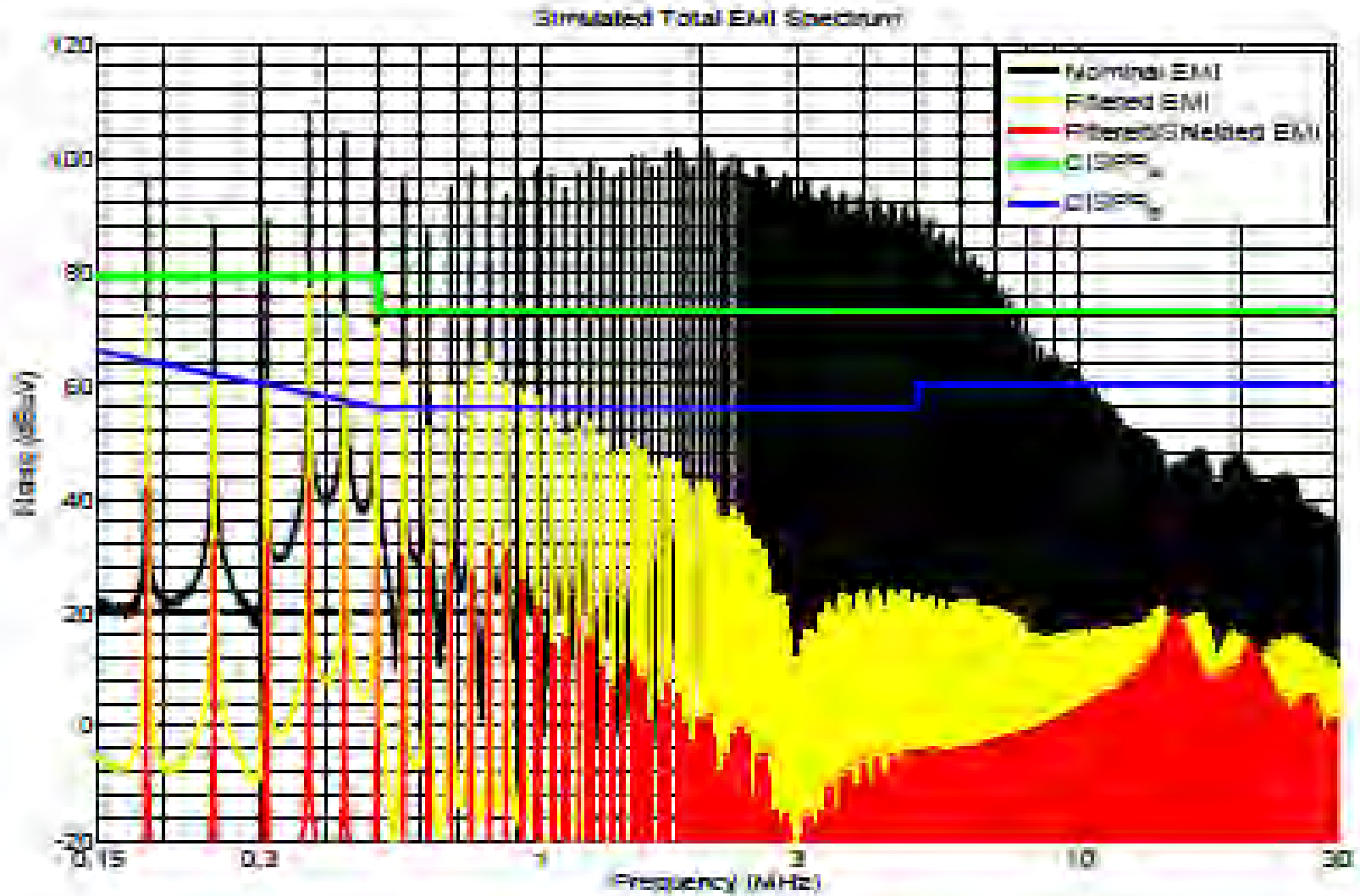
高级动态模型+封装寄生参数提取：开通/关断特性

虚拟CE测试---考虑各种寄生参数影响

- Create geometric model in Q3D, Maxwell and solve
- Model active components from datasheet
- Model all passive components using impedance analyzer
- Create and solve transient model in Simplorer
- Perform FFT

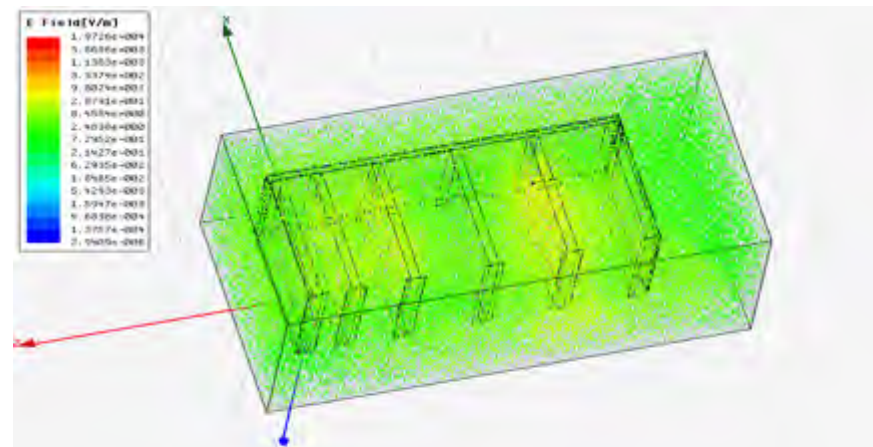
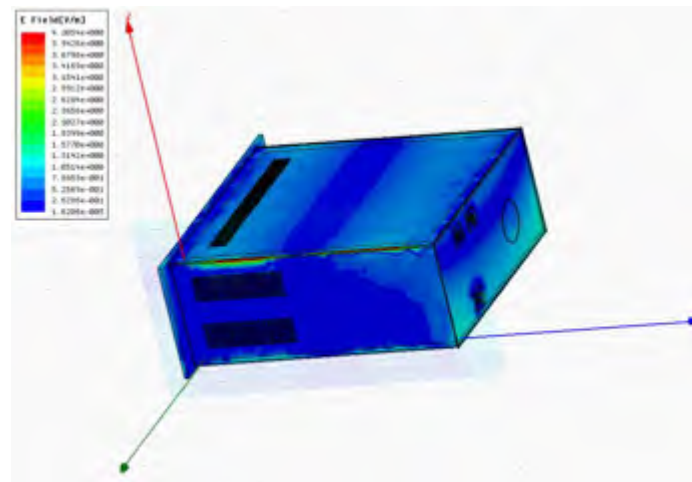
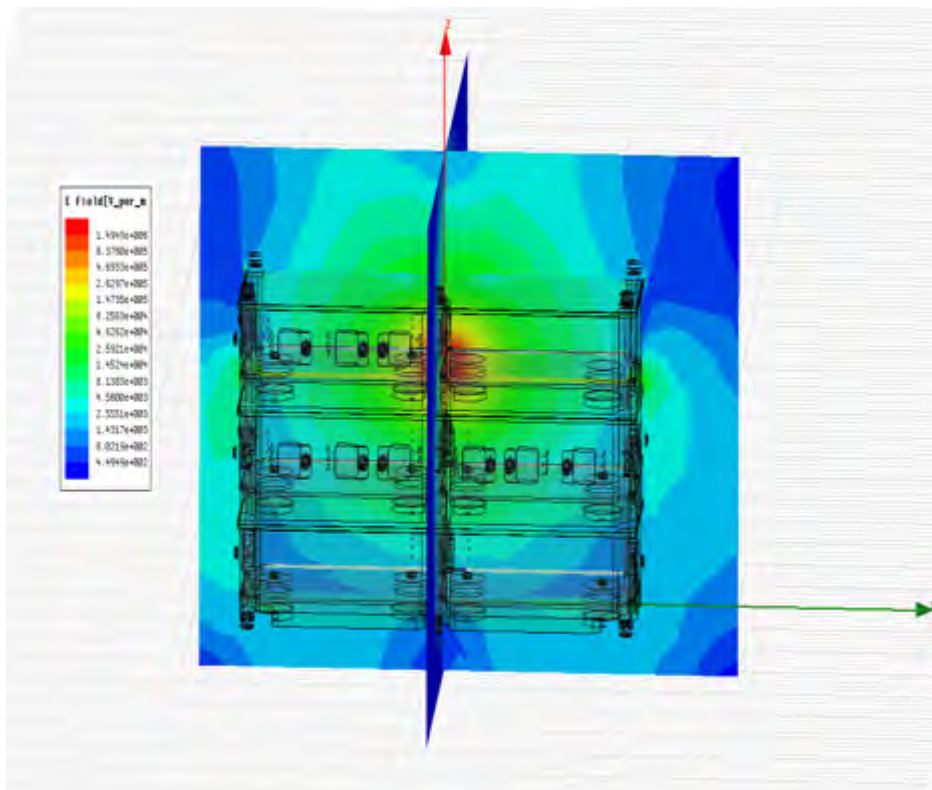


虚拟CE测试---方案优化

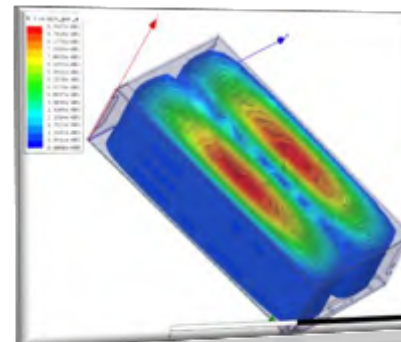
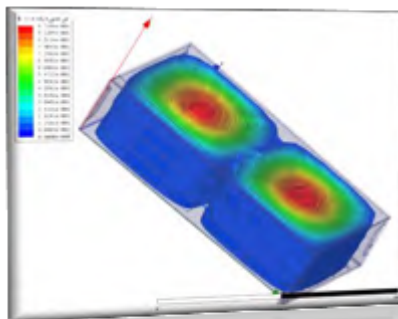
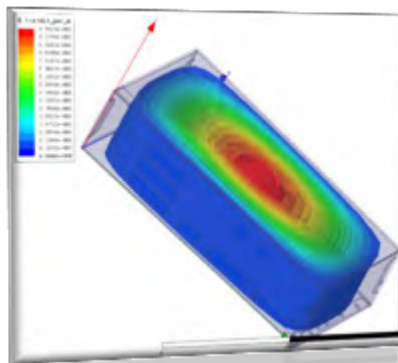


设备布局、电磁泄漏及屏蔽特性分析

- 在机箱接口处的孔缝是电磁辐射泄露的主要原因



机箱谐振仿真评估布局热点



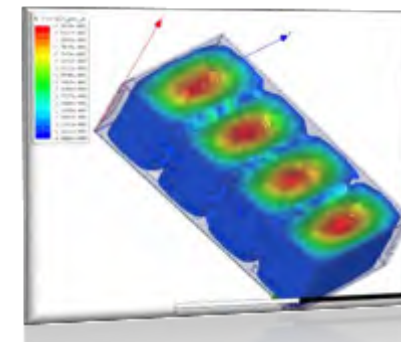
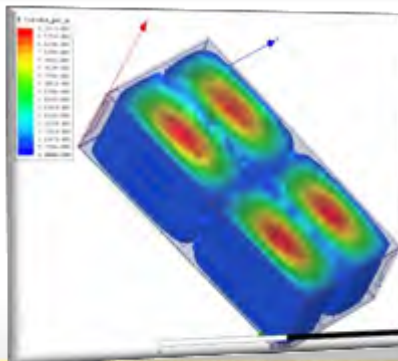
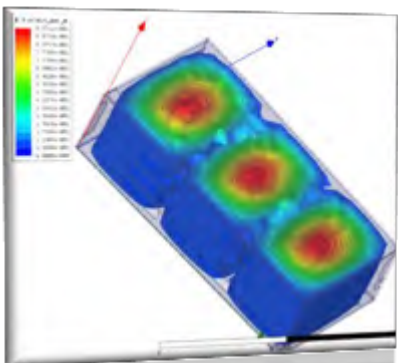
Solutions: EMI - HawkEigemode

Simulator:
 Design Variation:
 Profile | Convergence | Eigemode Data | Mesh Statistics |

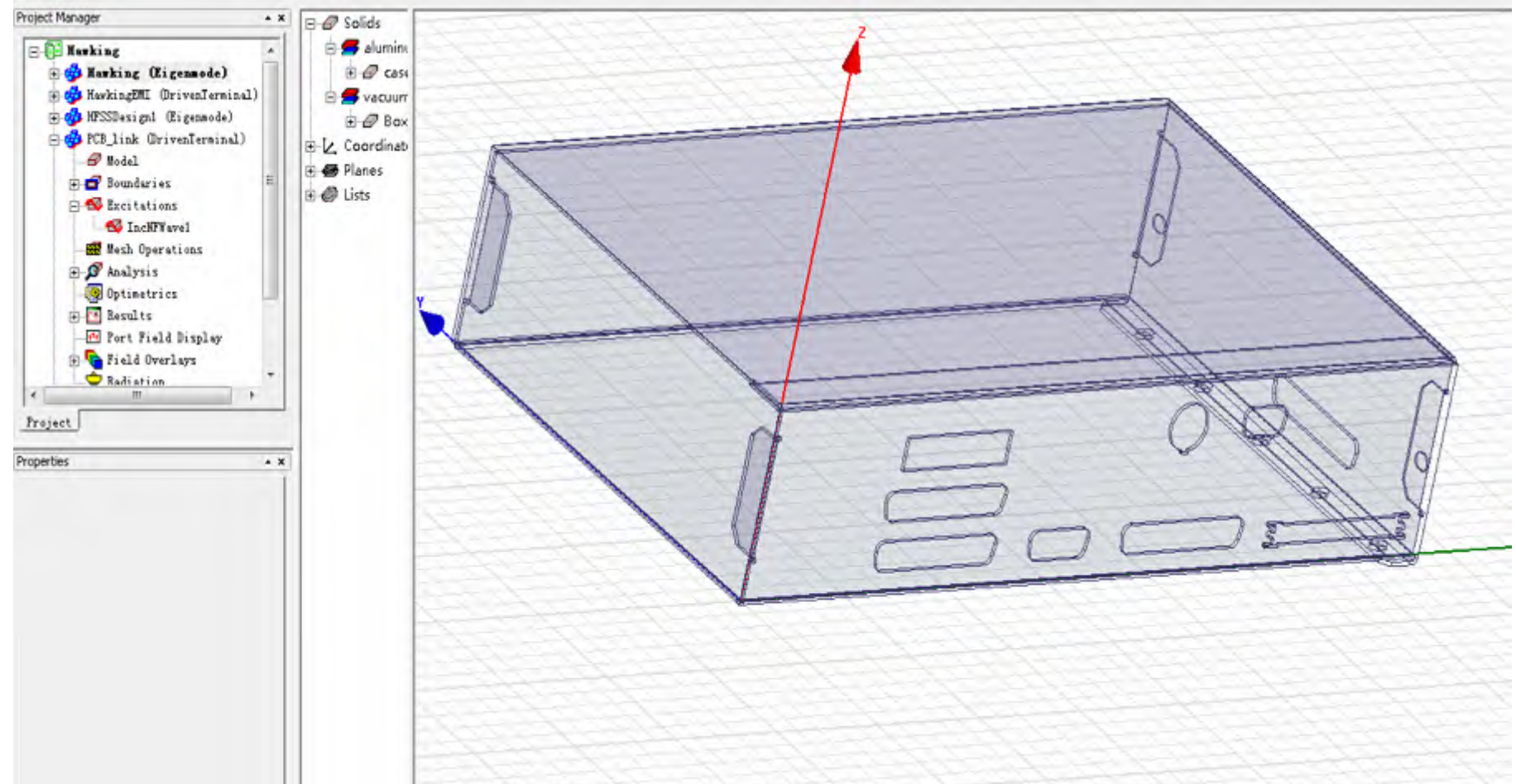
Solved Modes:

Eigemode	Frequency (GHz)	Q
Mode 1	0.895272 +j1.21789e-005	35112.8
Mode 2	1.15895 +j1.38191e-005	41918.5
Mode 3	1.52177 +j1.66599e-005	49674.5
Mode 4	1.53629 +j1.56973e-005	40937.9
Mode 5	1.71095 +j1.73947e-005	49180.2
Mode 6	1.94598 +j1.74949e-005	59615.6

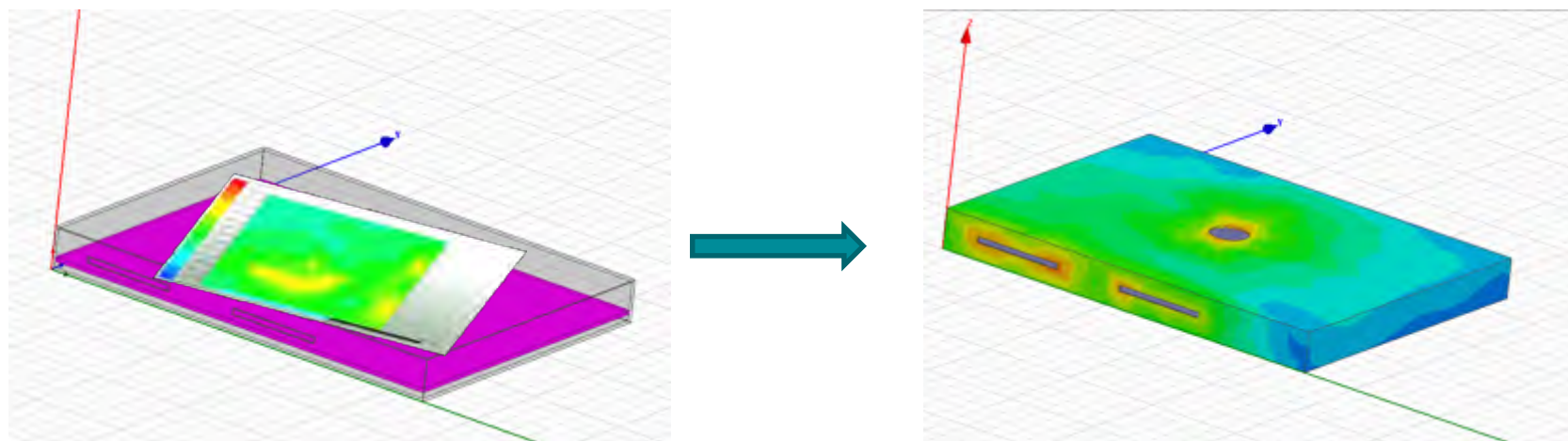
各个谐振频率的电场分布不同，尤其要关注高速信号经过的区域。



机箱/PCB协同仿真



机箱/PCB协同仿真



将PCB辐射源导入机箱结构，协同仿真设备级EMC。

虚拟设备RE测试

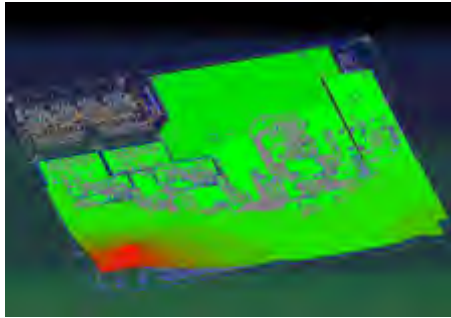
RADIATED EMISSIONS

This example shows radiated emissions (using a Quasi Peak detector) that are captured by the bi-conical antenna for every angular position of the PCB simulated in SIwave.

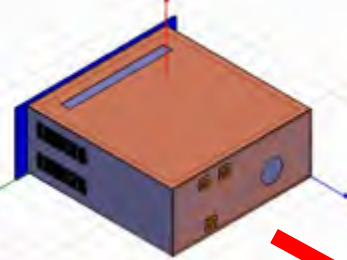
PCB MODEL COURTESY OF 

场到场链接

A noise analysis by Slwave



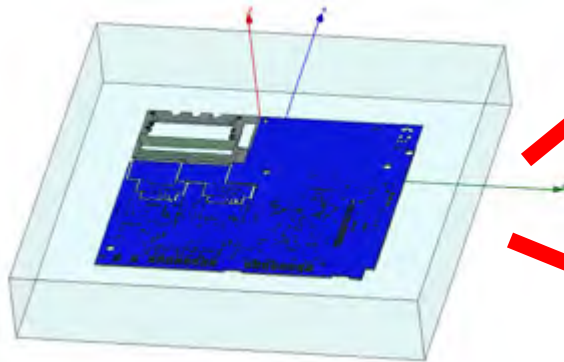
A excitation source



Slwave to HFSS

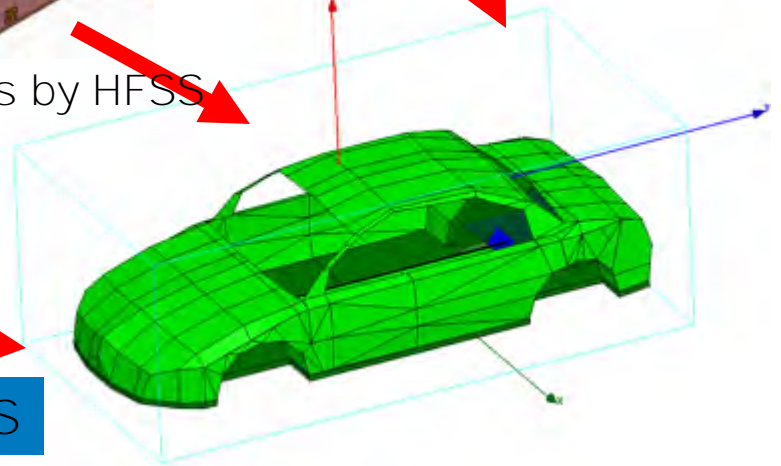
Slwave to HFSS

A ECU analysis by HFSS

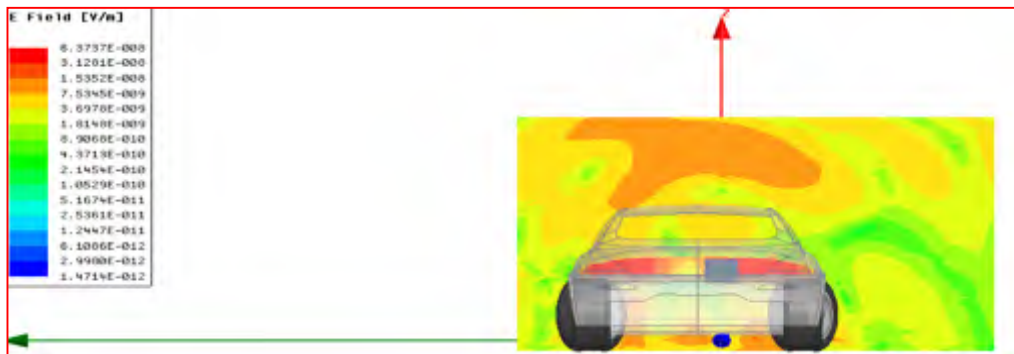


A EM analysis by HFSS

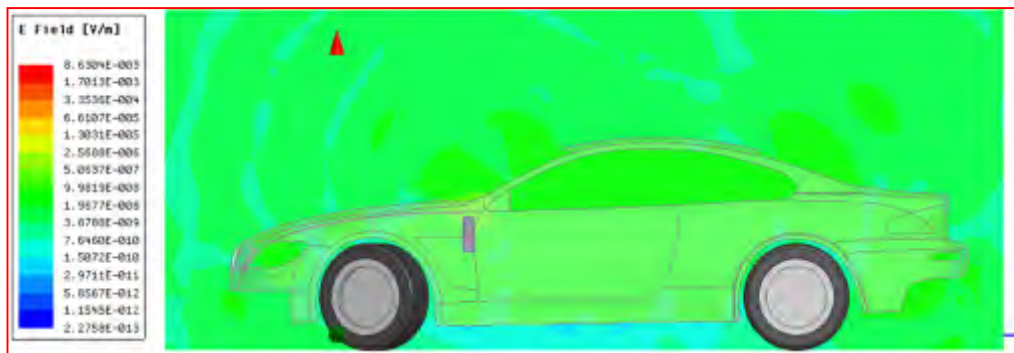
HFSS to HFSS



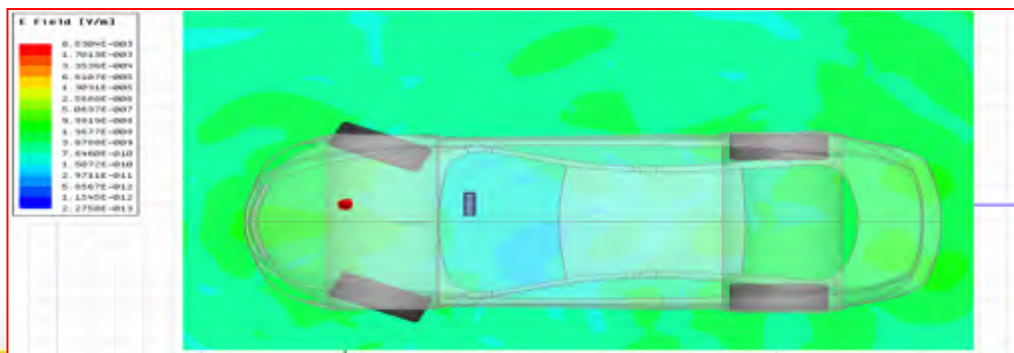
RE辐射测试仿真---整车EMC辐射



XZ 平面电场



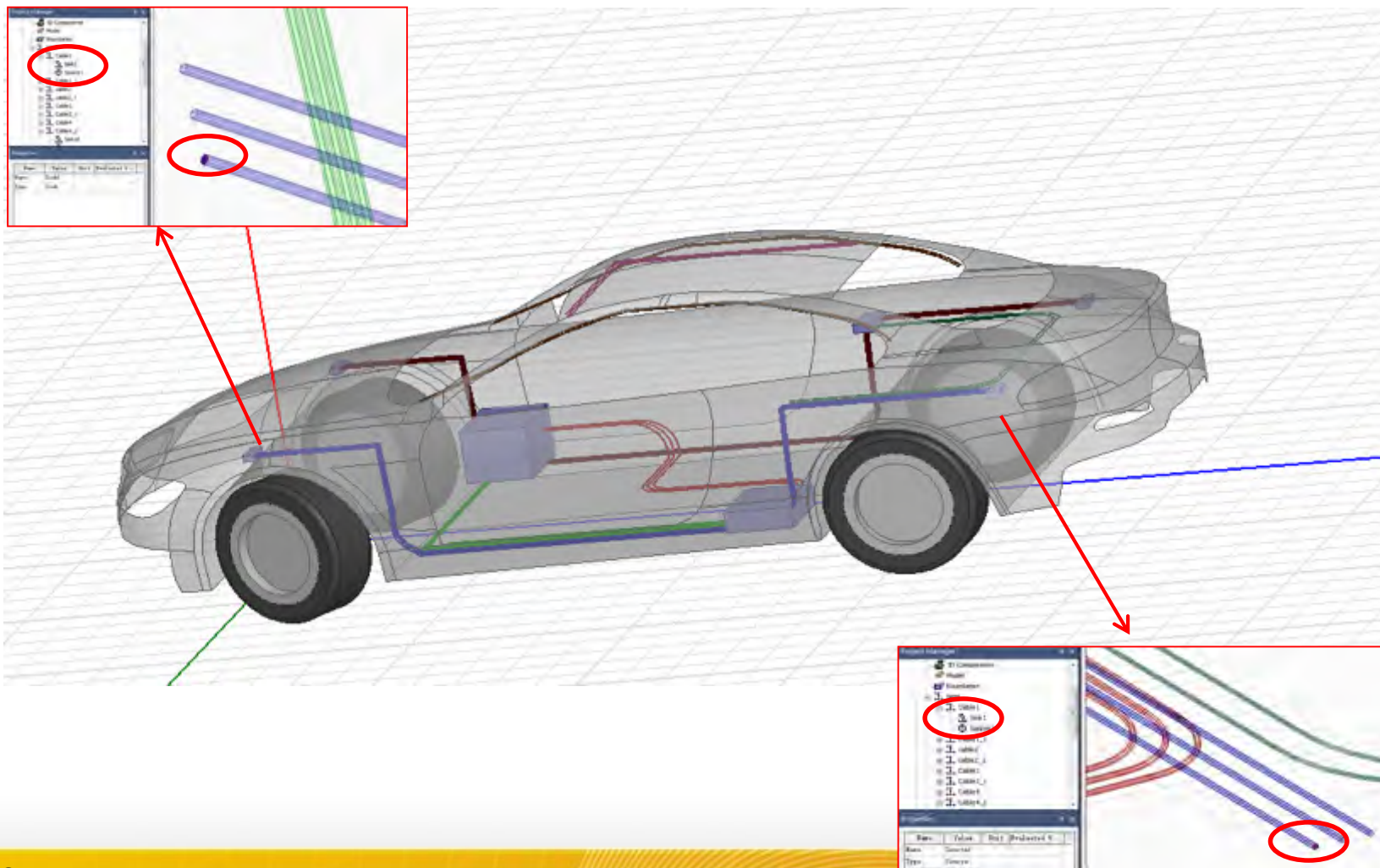
YZ平面电场



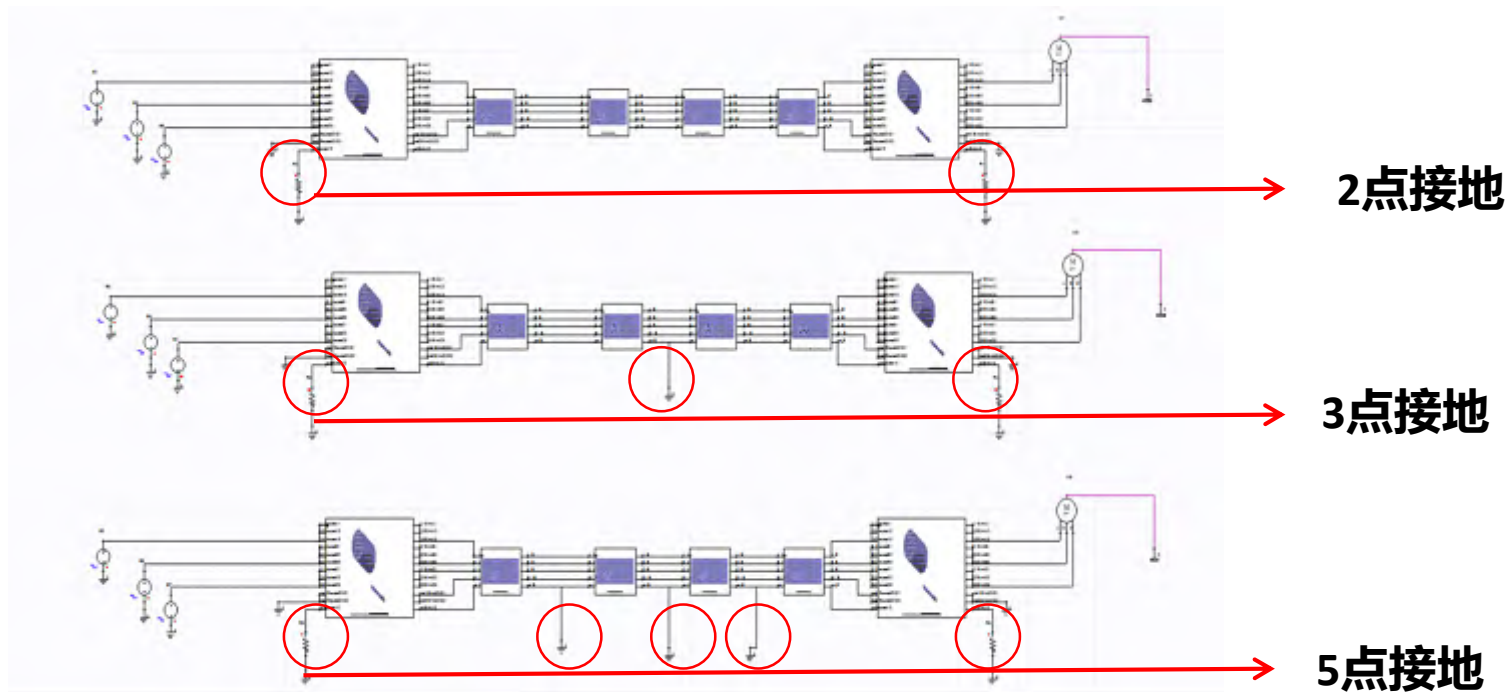
XY平面电场

线缆干扰分析---车体线缆电磁仿真

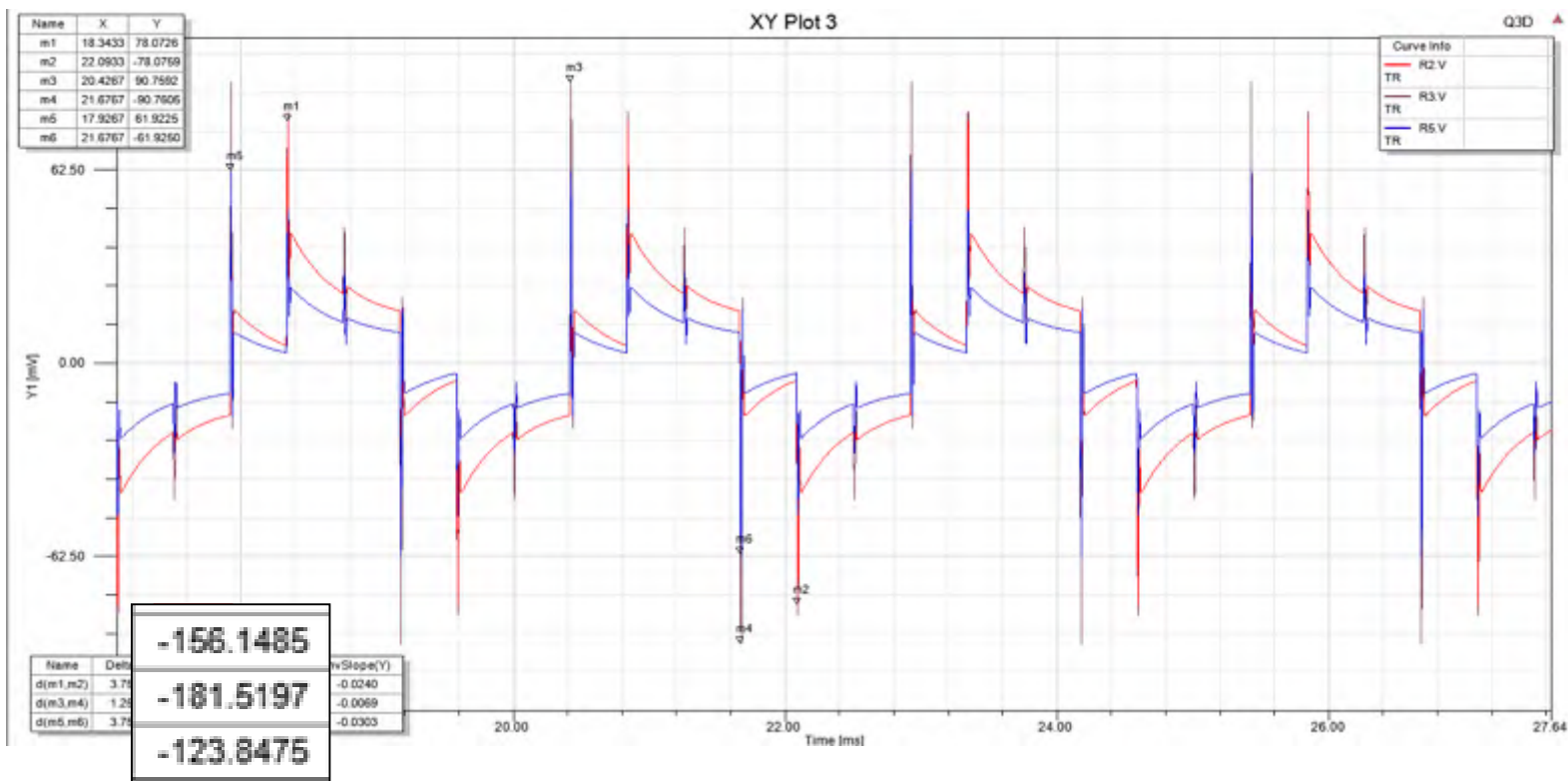
通过定义每根线缆的Source和Sink，可得到车内所有线缆的传输和耦合特性。



线缆干扰优化---接地点变化

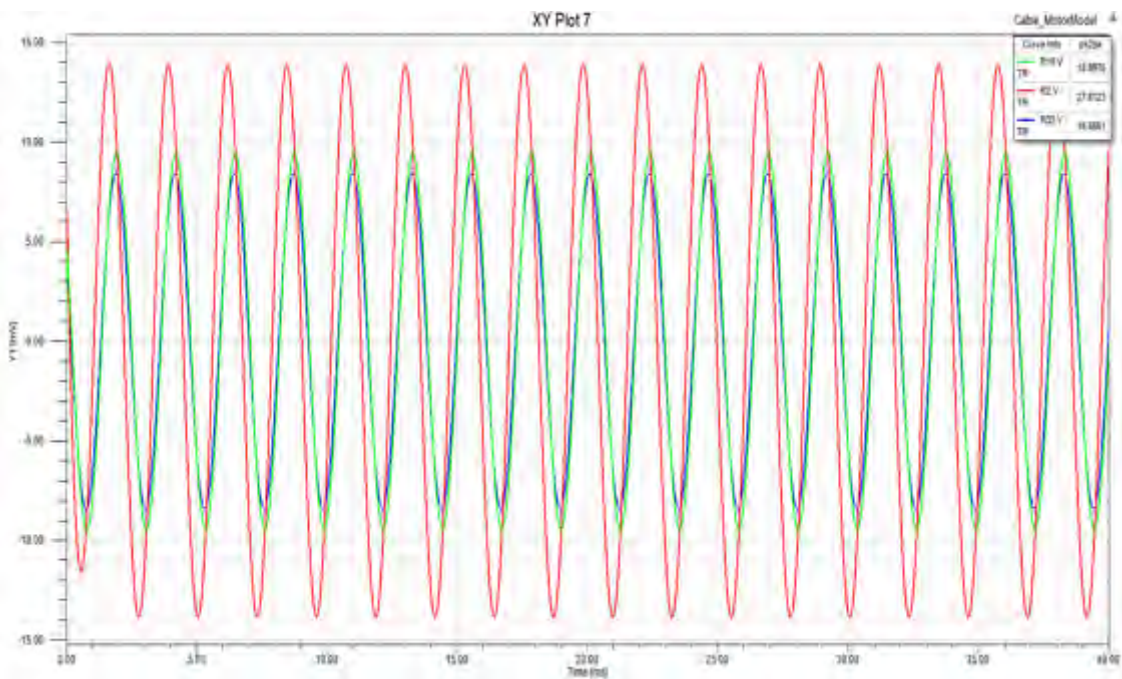


线缆干扰优化---接地点变化



- 表格中由上至下，分别为2/3/5三种接地方式的噪声波形，5点接地的噪声明显最小。

线缆屏蔽方式优化



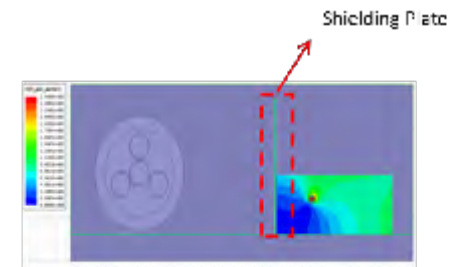
红：无屏蔽
 绿：屏蔽1
 蓝：屏蔽2



无屏蔽,
 最大电场幅度 $2.74e3$ V/m



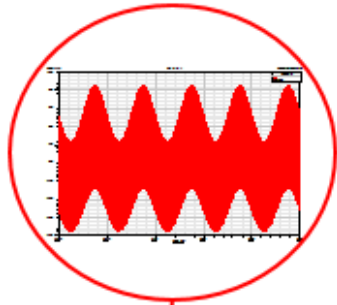
屏蔽1,
 最大电场幅度 $1.8e03$ V/m



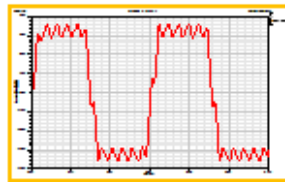
屏蔽2,
 最大电场幅度 $0.256e3$ V/m

场路协同分析，模拟系统真实工况

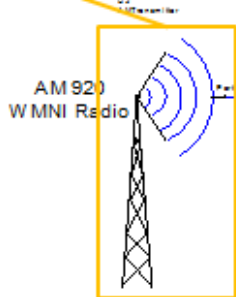
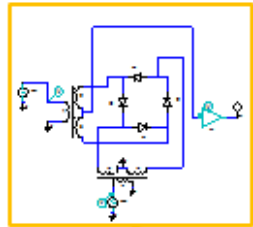
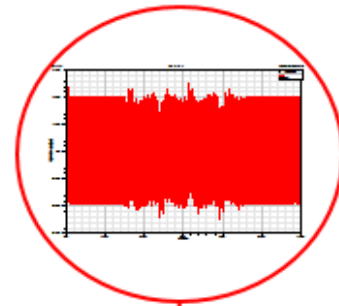
AM modulated waveform



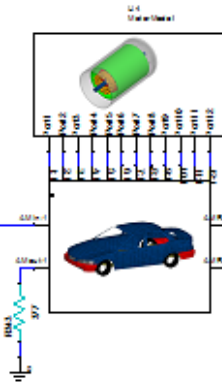
Motor noise waveform



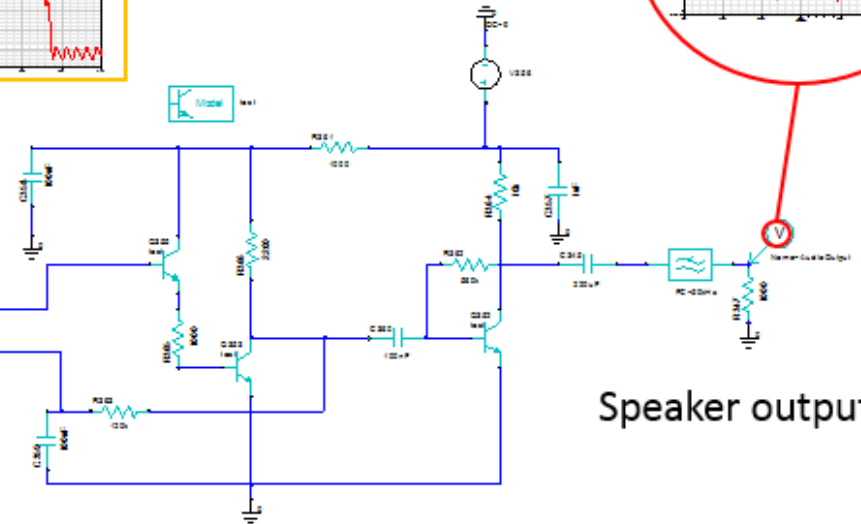
Audio signal



AM Modulated Signal generating sub-circuit



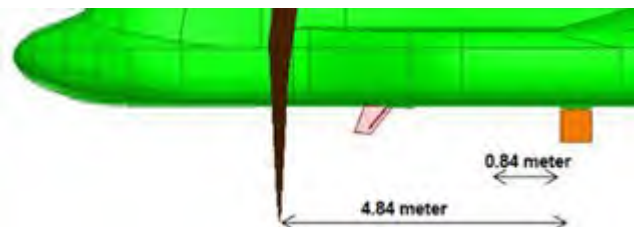
HFSS model with motor as noise source



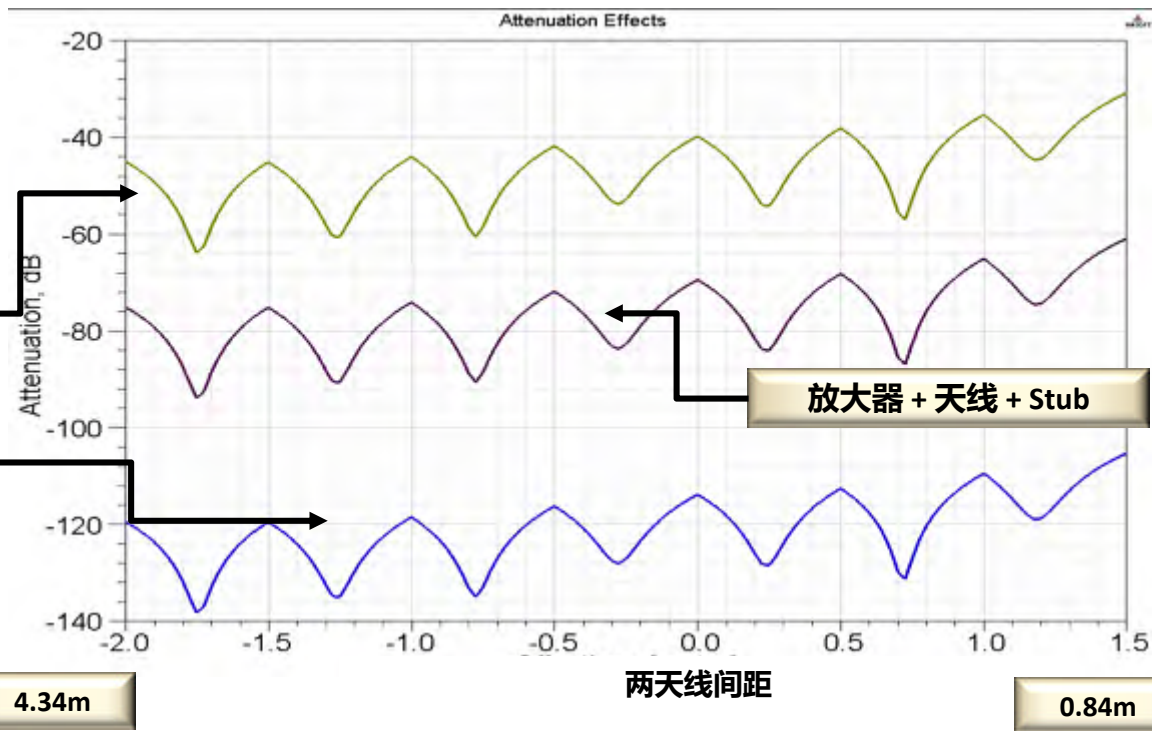
AM receiver circuit

Speaker output

天线互耦抑制仿真分析



高频段接收到低频段的互耦干扰 Vs. 天线间间距



仅放大器与天线

放大器 + 天线 + 滤波 + stub

放大器 + 天线 + Stub

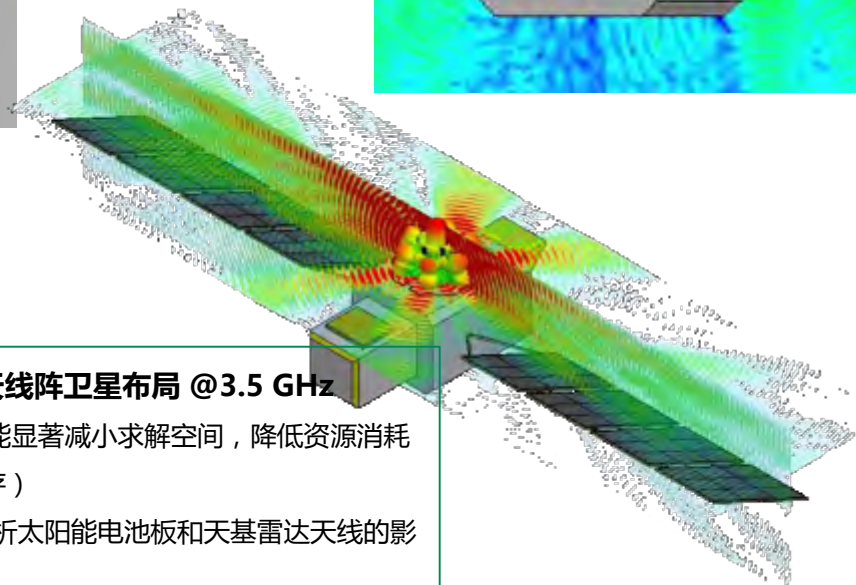
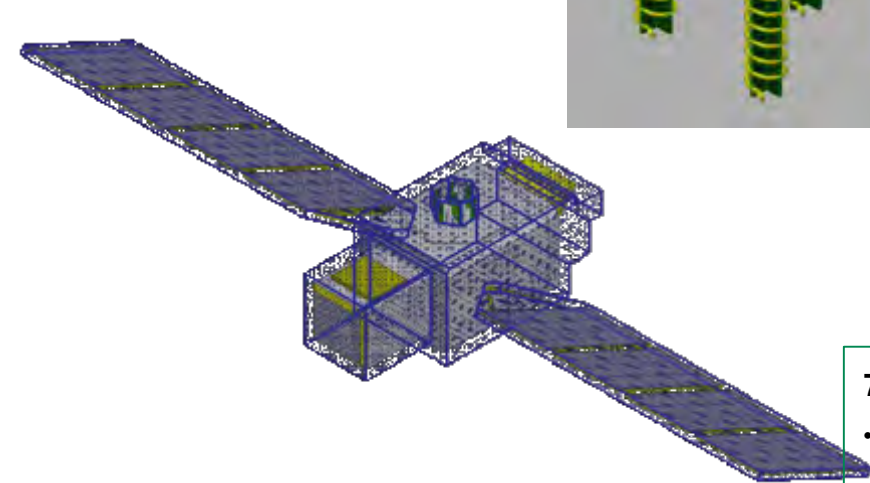
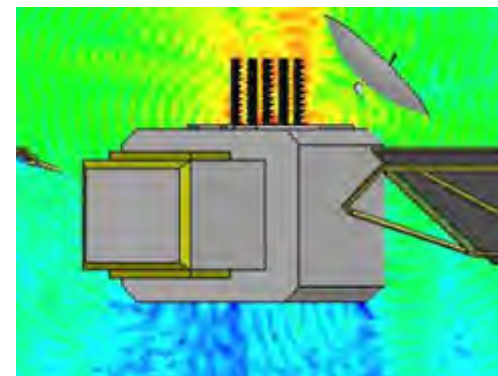
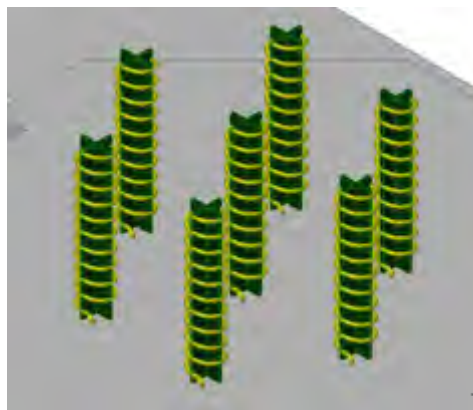
UHF-VHF Antenna

4.34m

两天线间距

0.84m

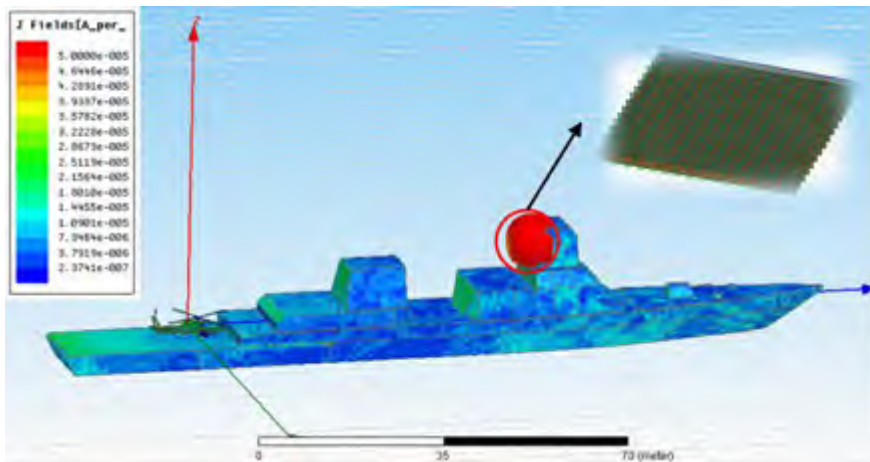
卫星天线布局



7单元螺旋天线阵卫星布局 @3.5 GHz

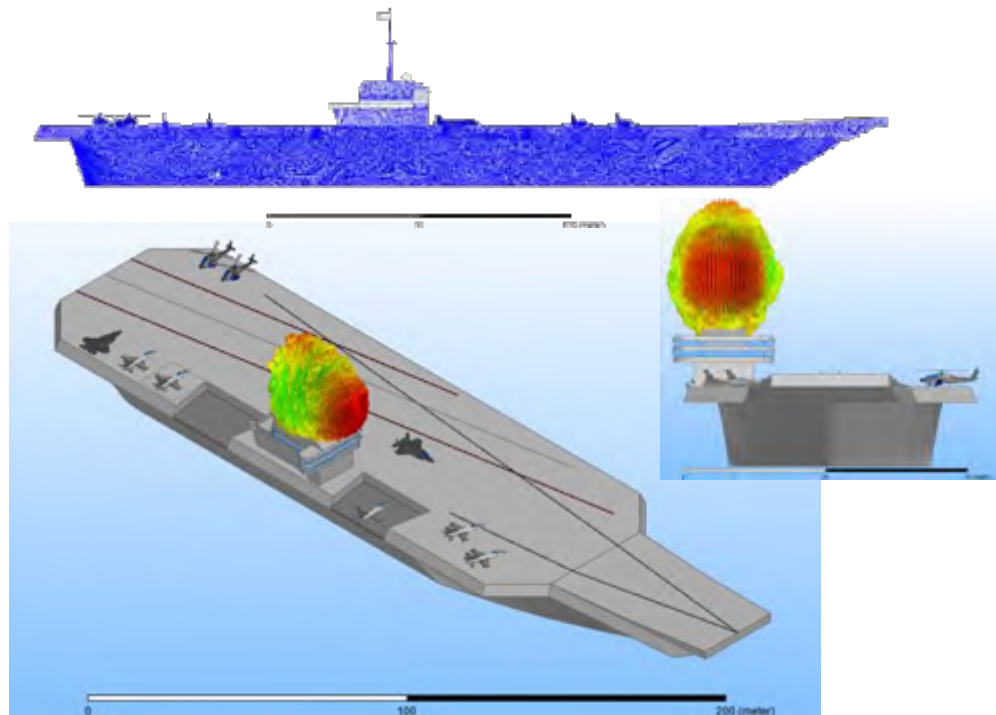
- FE-BI 技术能显著减小求解空间，降低资源消耗（21GB内存）
- 可进一步分析太阳能电池板和天基雷达天线的影响

舰船天线布局



256单元天线阵舰船布局及与直升机载天线杂散干扰仿真

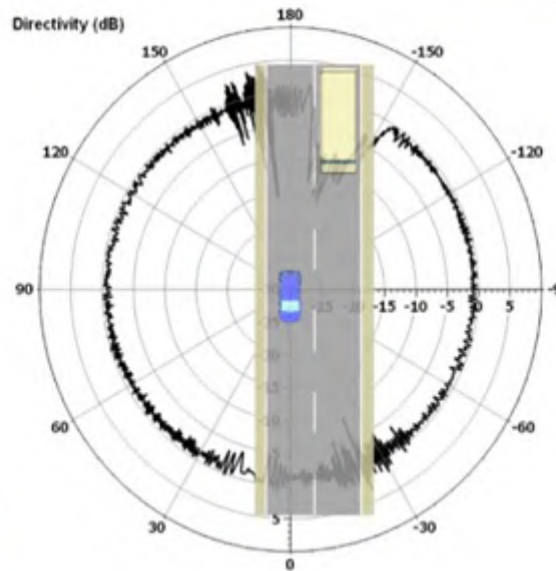
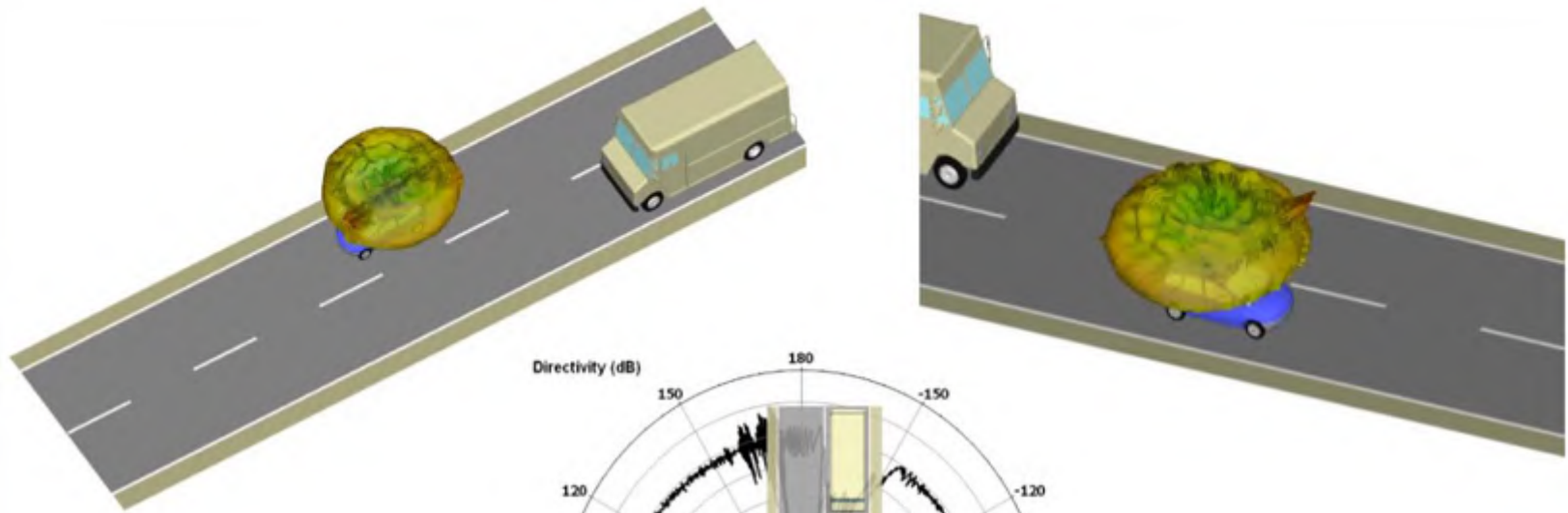
- 天线阵在10GHz带内的舰船布局仿真
- 天线阵350MHz带外与舰载直升机上天线的杂散干扰仿真
- 仿真结合了HFSS 有限大阵列仿真、HFSS-IE 区域分解等多项先进技术



航母天线塔布局仿真

- 2单元喇叭天线在航母上的布局仿真

超车过程中电磁性能分析



ANSYS



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