

Maxwell UDO 脚本： 输出二维傅里叶分析结果

谭洪涛、王杨

ANSYS China

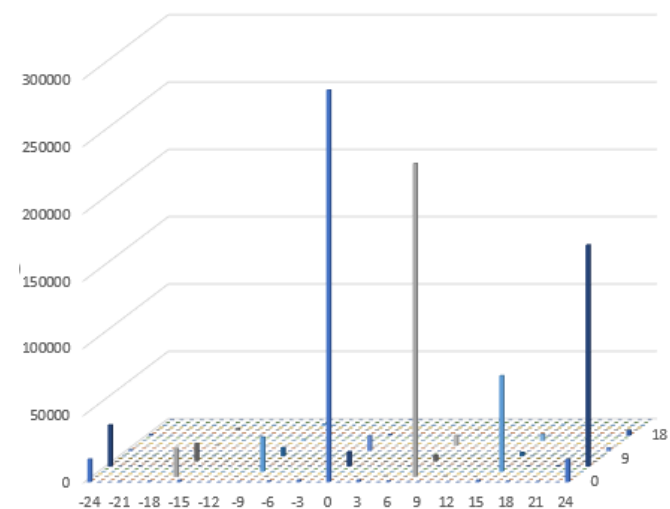
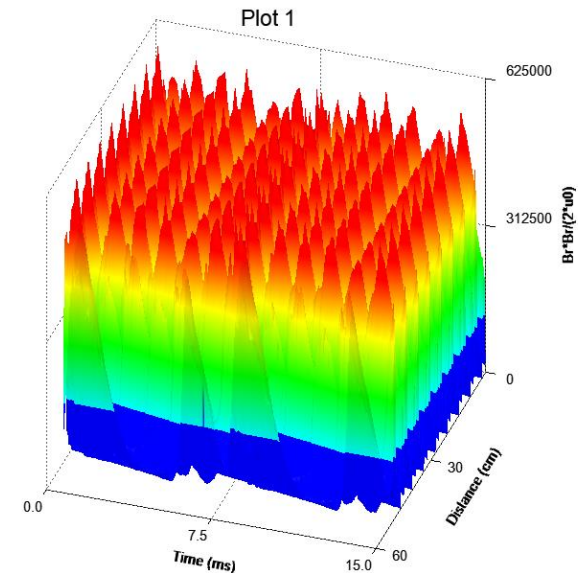


背景

- 电机的振动噪声是当前电机厂商重点关注的问题
- 电机振动噪声的主要激励源是定子受到的时变电磁力，它与结构模态叠加，在某些频段引起谐振
- 削弱电机振动幅度的关键是削弱对应阶次电磁力幅值，电机中的电磁力是非常复杂的，它是时间和空间的函数，包含了时间和空间谐波
- 为了提取某一时间、空间次数的电磁力谐波幅值，必须用到二维傅里叶分析，Maxwell目前没有该功能，为此，我们基于AEDT的UDO框架开发了专用于二维傅里叶分析的脚本
- 利用该脚本，用户可轻松提取电磁力时空谐波幅值，并将其作为优化设计的目标函数，进而实现从源头上进行电机的减振降噪优化设计

脚本介绍

- 电机转子旋转时，气隙圆周中产生的空间电磁力密度波形具有时空二维属性
- 我们通常对有限元仿真得到的时空电磁力波数据进行二维傅里叶分析（FFT2D），获得不同时、空阶次分量的幅值，以判断其对振动的贡献
- 在Maxwell中直接进行FFT2D比较困难
- 为此，我们开发了用于FFT2D的UDO脚本，功能包括：
 - 输出用户指定的任意时、空阶次幅值
 - 导出所有FFT2D结果矩阵到csv文件
- 利用该脚本即可实现对电磁力某时、空阶次幅值的优化



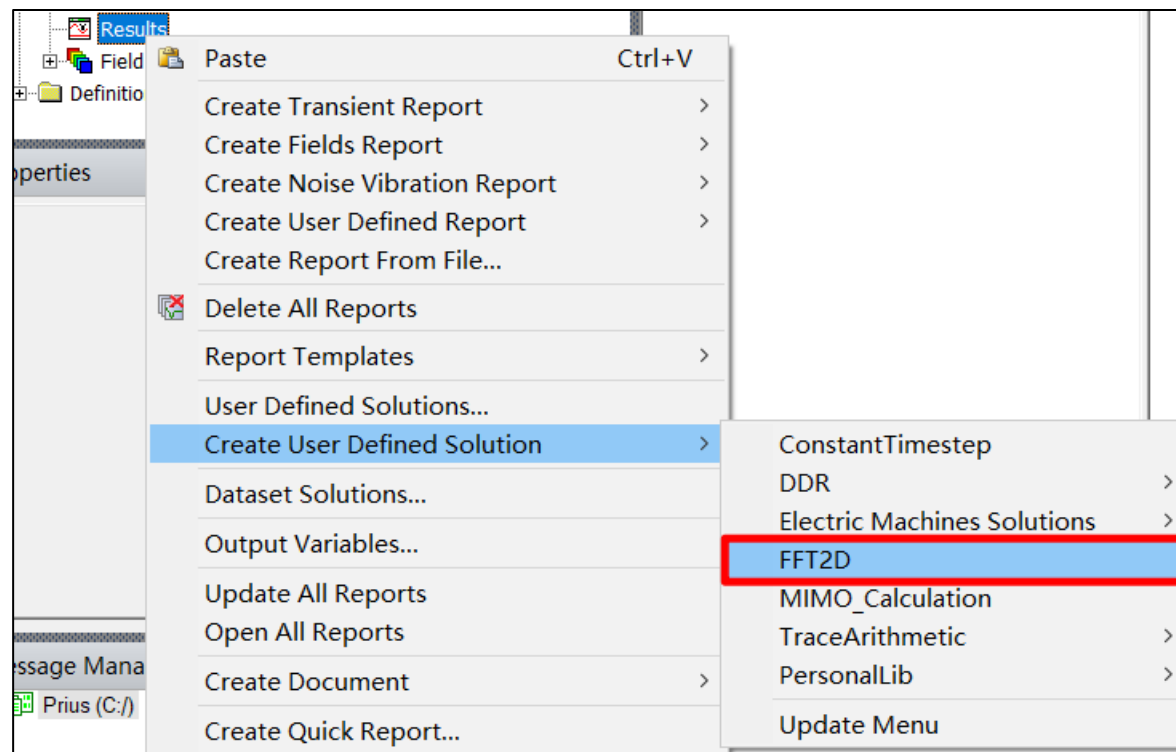
FFT2D UDO 插件安装

- 将 FFT2D.py 复制到以下路径

- C:\Program Files\AnsysEM\AnsysEM???.?\.Win64\syslib\UserDefinedOutputs

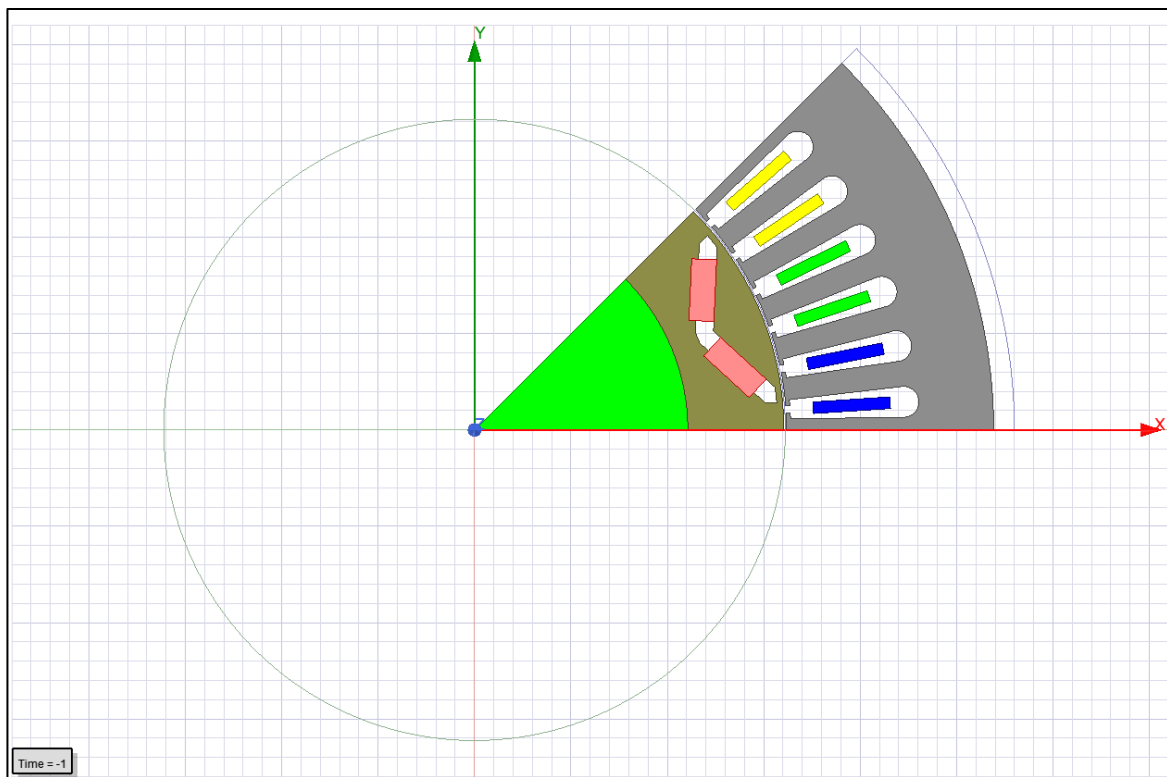
- 选择菜单 Create User Defined Solution > Update Menu

- 加载 FFT2D 脚本



FFT2D UDO 插件使用方法

- 在模型中画出查看电磁力的路径（完整圆）
- 在该圆形路径的属性窗口，取消勾选Model选项



Name	Value	Unit	Evaluated
Name	Circle1		
Orientation	Global		
Model	<input type="checkbox"/>		
Group	Model		
Display Wirefr...	<input type="checkbox"/>		
Material App...	<input type="checkbox"/>		
Color	<input type="text" value=""/>		
Show Direction	<input type="checkbox"/>		
< <input type="text" value=""/> >			
Attribute <input type="text" value=""/>			

场计算器添加电磁力密度计算公式

• 添加Br和Bt

1	Input → Quantity → B
2	Vector → X Form → ToCylindrical
3	Vector → Scal? → ScalarX

1	Input → Quantity → B
2	Vector → X Form → ToCylindrical
3	Vector → Scal? → ScalarY

• 添加Fr

- 径向电磁力密度公式 $(B_r^2 - B_t^2) / \mu_0 / 2$

Named Expressions		
Name	Expression	
Core_Loss	Smooth(Core-Loss)	
Total_Loss	Smooth(Total-Loss)	
Br	ScalarX(ToCylindrical(<Bx,By,0>,offset<0mm, 0mm, 0mm>))	
Bt	ScalarY(ToCylindrical(<Bx,By,0>,offset<0mm, 0mm, 0mm>))	
Fr	Smooth(1/((-*(Br, Br), *(Bt, Bt)), 1.25663706143592E-06), 2))	

FFT2D UDO插件设置

Editing User Defined Solution: t12s0

Solution:

Description: FFT2D

Select Probes:

Input	Type	Description	Assignment	Edit
FieldReport	double	Select a transient field quantity	Fr	1

Specify Properties:

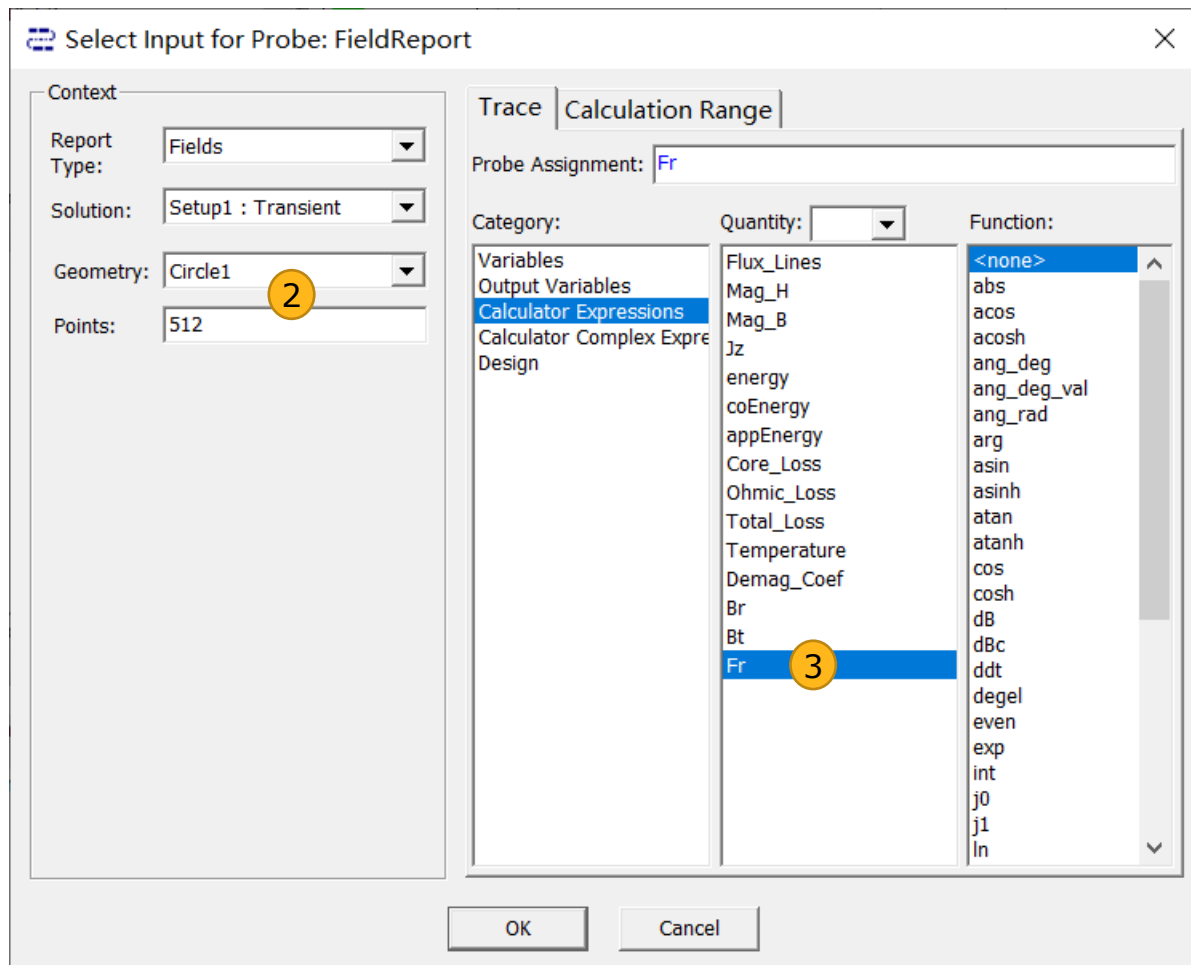
Name	Value	Unit	Description
Order of time domain	12		Multiples of fundamental electric frequency
Order of space domain	0		Number of spatial modes, can be positive or negative
Export FFT2D datatable ?	No		Select Yes or No
Maximum time order	0		The largest number of time domain order to export, in
Maximum space order	0		The largest number of space domain order to export, i

< >

OK Cancel

1. 点击按钮

FFT2D UDO插件设置

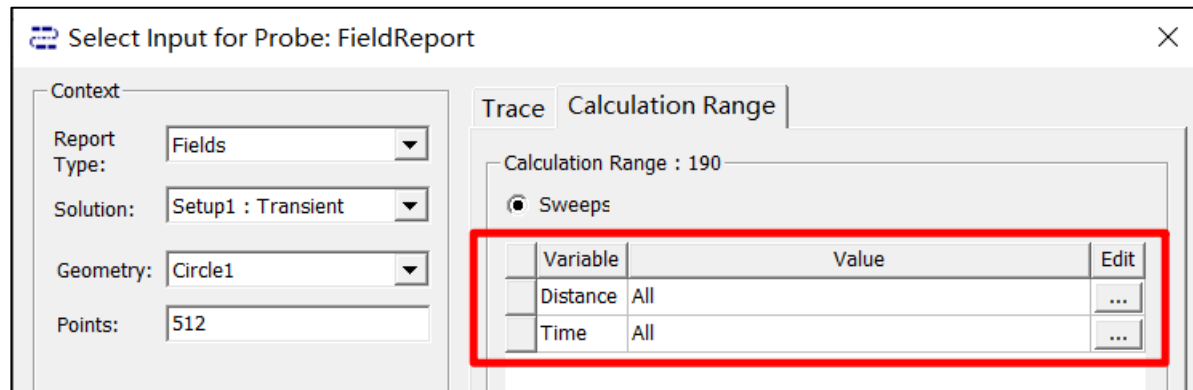


1. 点击按钮

2. 选择路径，设置取点数

- 取点数不宜过大
- 推荐512，配合128时间步

3. 填写电磁力表达式



FFT2D UDO插件设置

Editing User Defined Solution: t12s0

Solution:

Description: FFT2D

Select Probes:

Input	Type	Description	Assignment	Edit
FieldReport	double	Select a transient field quantity	Fr	...

Specify Properties:

Name	Value	Unit	Description
Order of time domain	12		Multiples of fundamental electric frequency
Order of space domain	0		Number of spatial modes, can be positive or negative
Export FFT2D datatable ?	No		Select Yes or No
Maximum time order	0		The largest number of time domain order to export, in
Maximum space order	0		The largest number of space domain order to export, i

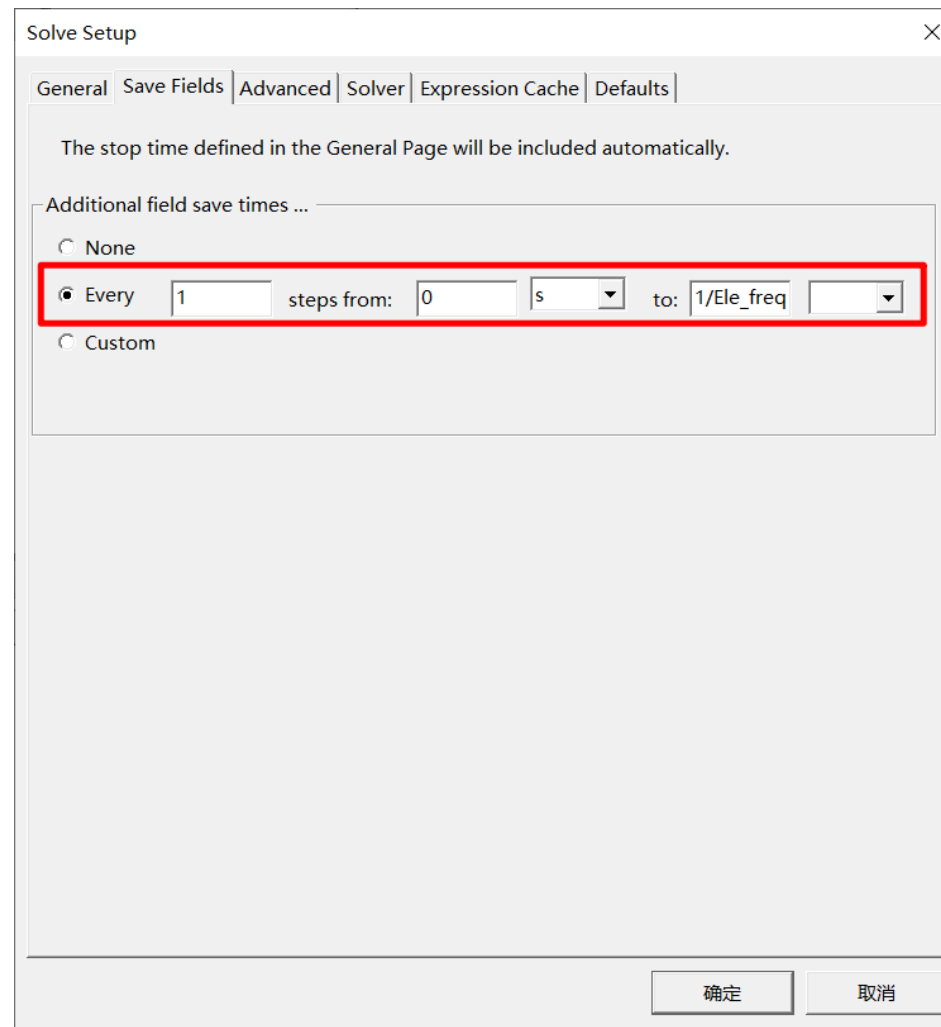
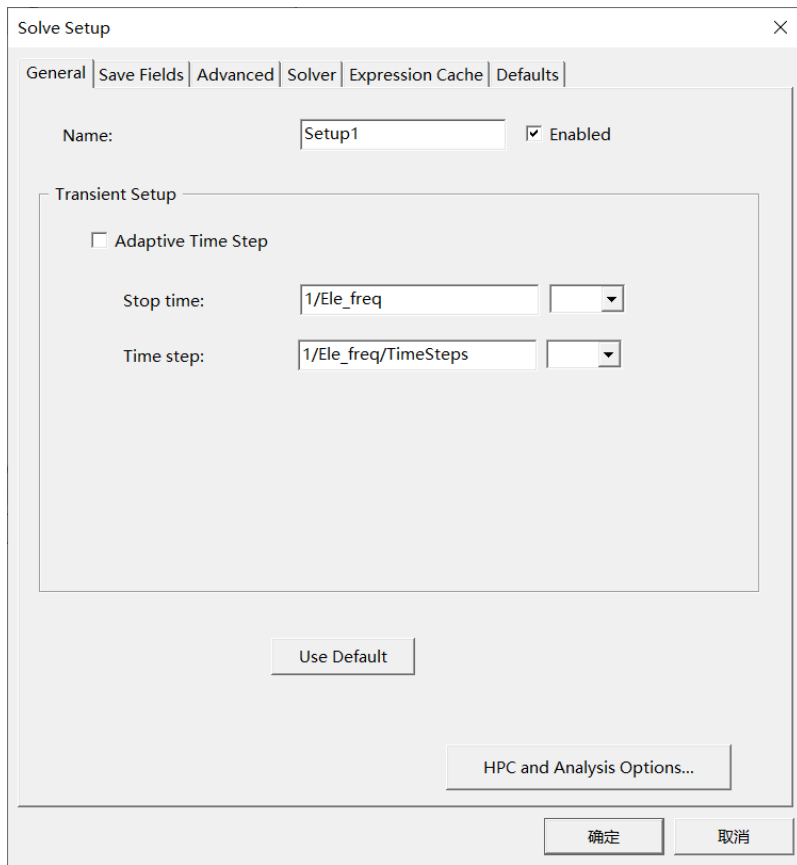
< >

OK **5** Cancel

1. 点击按钮
2. 选择路径，设置取点数
3. 填写电磁力表达式
4. 设置参数
 1. 定义时间阶数
 2. 定义空间阶数，可为负数
 3. 是否导出FFT2D结果矩阵
 4. 导出最大时间阶数
 5. 导出最大空间阶数
5. 确定

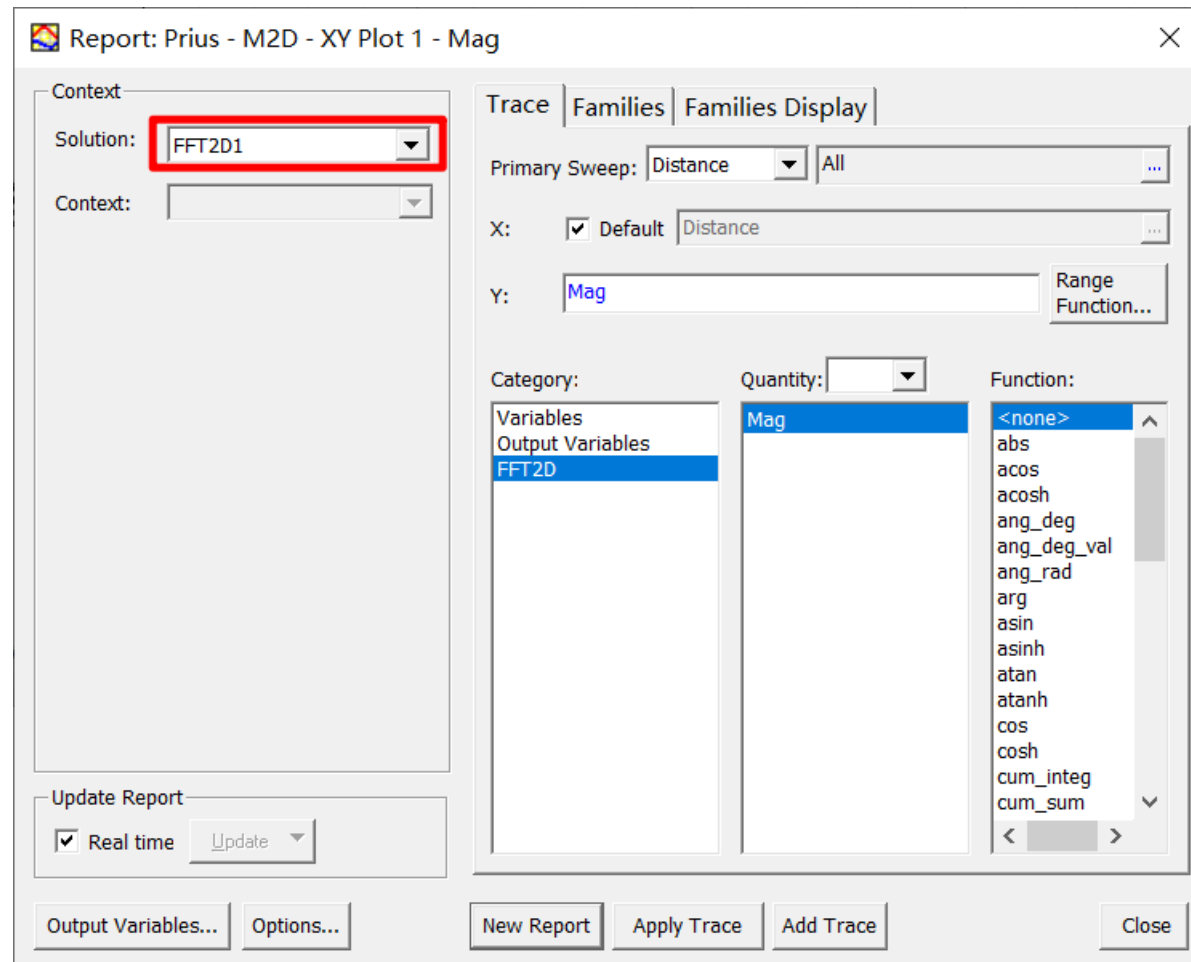
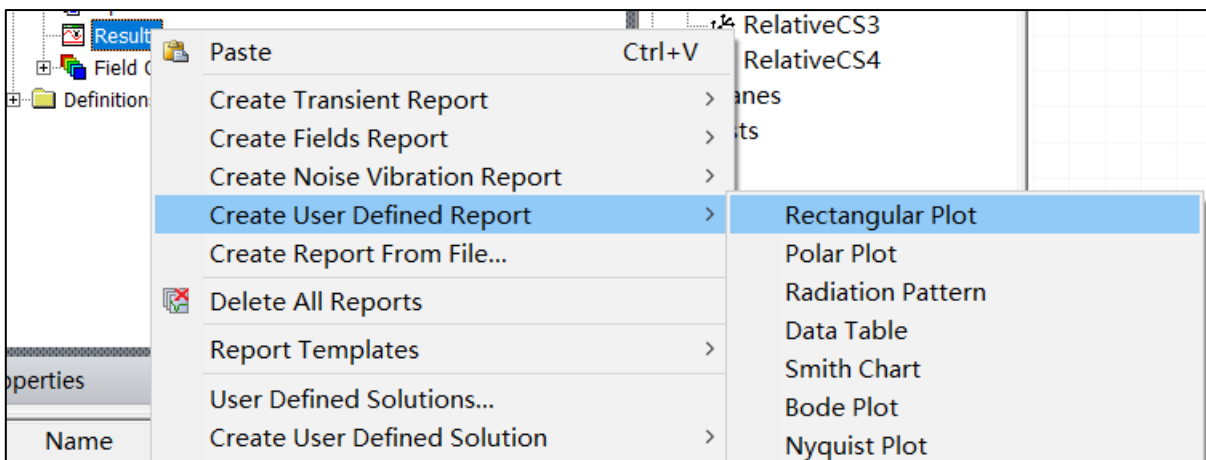
求解设置

- 只需计算一个电周期
- 保存每个时间步的场结果



查看结果

- 求解结束后
- 查看某次分量的幅值



查看FFT2D结果矩阵

- 脚本会在Maxwell工程文件同目录下生成FFT2D_data.csv文件
- 矩阵横轴对应空间阶次（包括负的阶次）、纵轴对应时间阶次

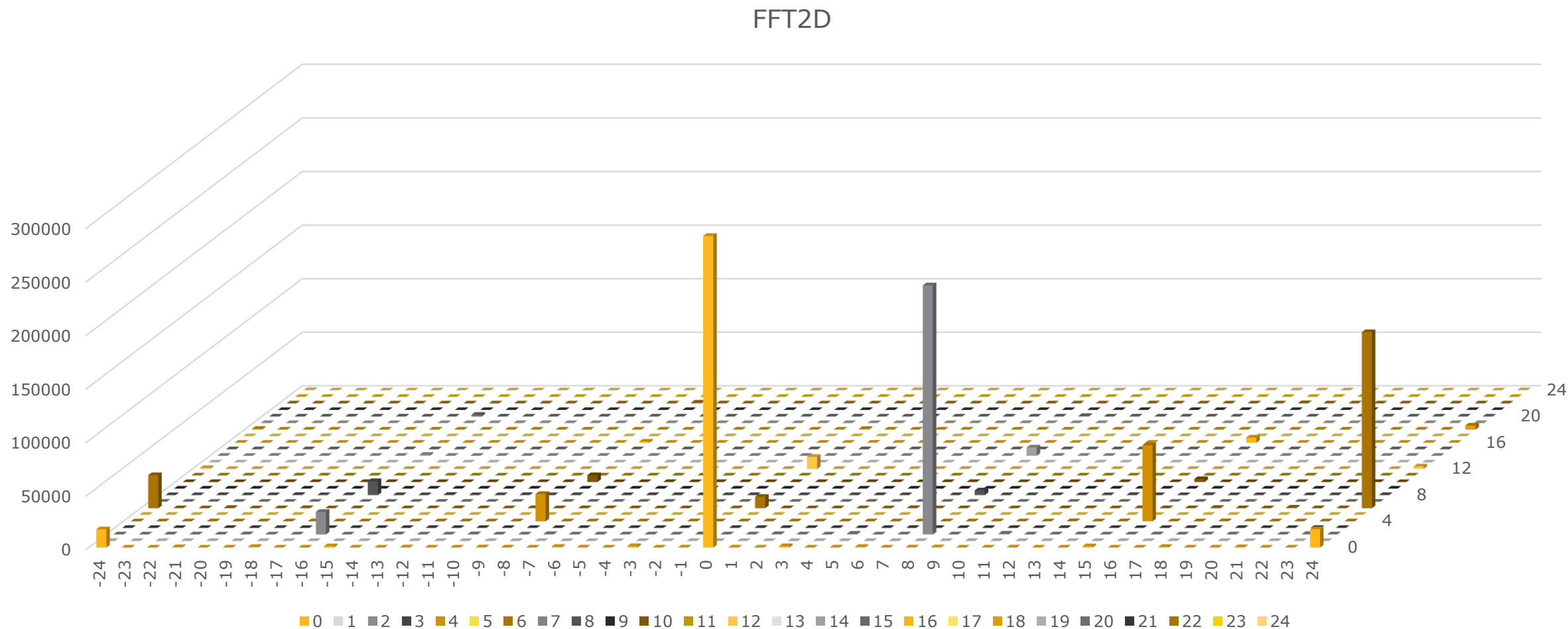
Space order →

	A	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	
1	Time\Space	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	
2	0	133.9724	40.54763	685.1617	96.01494	14.41645	1382.92	43.56714	90.50109	291147.3	90.50109	43.56714	1382.92	14.41645	96.01494	685.1617	40.54763	133.9724	2
3	1	0.000137	0.002211	0.000472	0.000447	0.000321	0.000398	0.000472	0.002255	时间0空间0	0.002029	0.000158	0.000245	0.000288	0.00031	0.000293	0.002186	0.000396	0
4	2	15.05897	465.821	15.66589	22.57424	61.60945	55.34378	10.08548	202.1785	68.35152	30.79035	349.5398	69.7025	18.06397	736.9956	24.70324	73.22168	232774.4	6
5	3	0.00016	0.002248	0.000207	0.000263	0.000261	0.000381	0.00023	0.001796	0.000134	0.002097	0.000341	0.000566	0.00027	0.000236	0.000365	0.002008	时间2空间8	0
6	4	25627.84	13.35297	11.5961	55.54643	7.879261	11.68043	61.94989	21.8114	22.23985	90.39115	21.41838	10.72934	45.80186	35.40878	13.41803	114.1015	40.73217	4
7	5	时间4空间-8	0.000329	0.000583	0.000324	0.000453	0.000259	0.000438	0.002489	0.000395	0.001883	0.000304	0.000271	0.000225	0.000333	0.000518	0.001708	0.000259	0
8	6	0.242554	35.47842	39.95196	8.740758	20.62173	14.33437	9.226134	11.42276	10695.12	35.50929	16.53025	24.09426	13.03039	19.22841	187.3139	14.95897	30.54558	1
9	7	0.000388	0.002032	9.66E-05	0.00042	0.000237	0.00032	0.00051	0.0018	时间6空间0	0.002091	9.18E-05	0.000237	0.000189	9.10E-05	0.000109	0.002317	0.000781	0
10	8	56.47969	121.8055	15.82802	62.92623	82.36761	10.71254	31.81047	110.8176	18.64117	30.63382	69.86993	29.95144	20.67891	31.16749	21.53969	13.16397	4483.55	2
11	9	8.24E-05	0.002677	0.000621	0.000238	0.000451	0.000201	0.000267	0.002116	0.000704	0.001973	0.000487	0.00029	0.000322	0.000413	0.000353	0.002205	0.000421	0
12	10	6456.274	35.51414	17.47969	44.71512	1.775759	13.82355	20.00741	8.073004	18.55351	42.59677	4.41889	23.0721	17.20826	10.43852	19.01511	54.64497	22.09863	0
13	11	0.000433	0.001511	0.000472	0.000379	0.000103	0.000384	0.000414	0.00188	0.00052	0.001846	0.000469	0.000346	2.49E-05	0.000353	0.000379	0.001449	0.000753	0
14	12	9.227702	7.916697	53.52682	13.68489	13.25266	117.4635	19.10079	58.15956	11316.14	42.91669	11.588	170.0503	8.358127	6.297697	86.77639	12.09994	29.29408	0
15	13	0.000243	0.002602	0.000192	0.000182	0.000552	0.000209	0.000216	0.001008	时间12空间0	0.002386	8.59E-05	3.93E-05	0.000427	0.000288	0.000121	0.002582	0.000579	0
16	14	4.131844	34.43245	8.058095	16.69422	7.668794	7.755419	19.26377	14.34232	26.48189	15.93135	17.19202	6.454107	17.2055	8.209971	23.97434	47.98427	7837.863	6
17	15	0.000724	0.002567	0.000403	0.000327	0.000343	0.000126	0.000385	0.002277	0.000701	0.001411	0.000515	0.000221	0.000303	0.000546	0.000177	0.001199	0.000512	0
18	16	1002.178	3.519335	7.223448	3.110057	5.712049	3.848148	26.08703	26.45456	5.910266	39.79487	7.540462	5.681839	2.077359	14.45245	18.30616	9.961607	28.37189	1

Time order ↓

查看FFT2D结果柱状图

- 使用Excel绘制三维柱状图



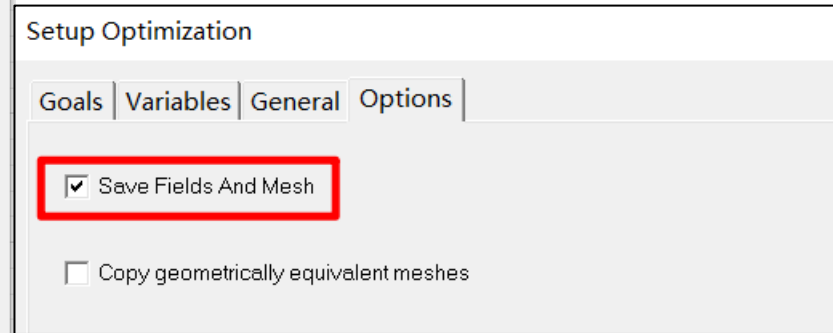
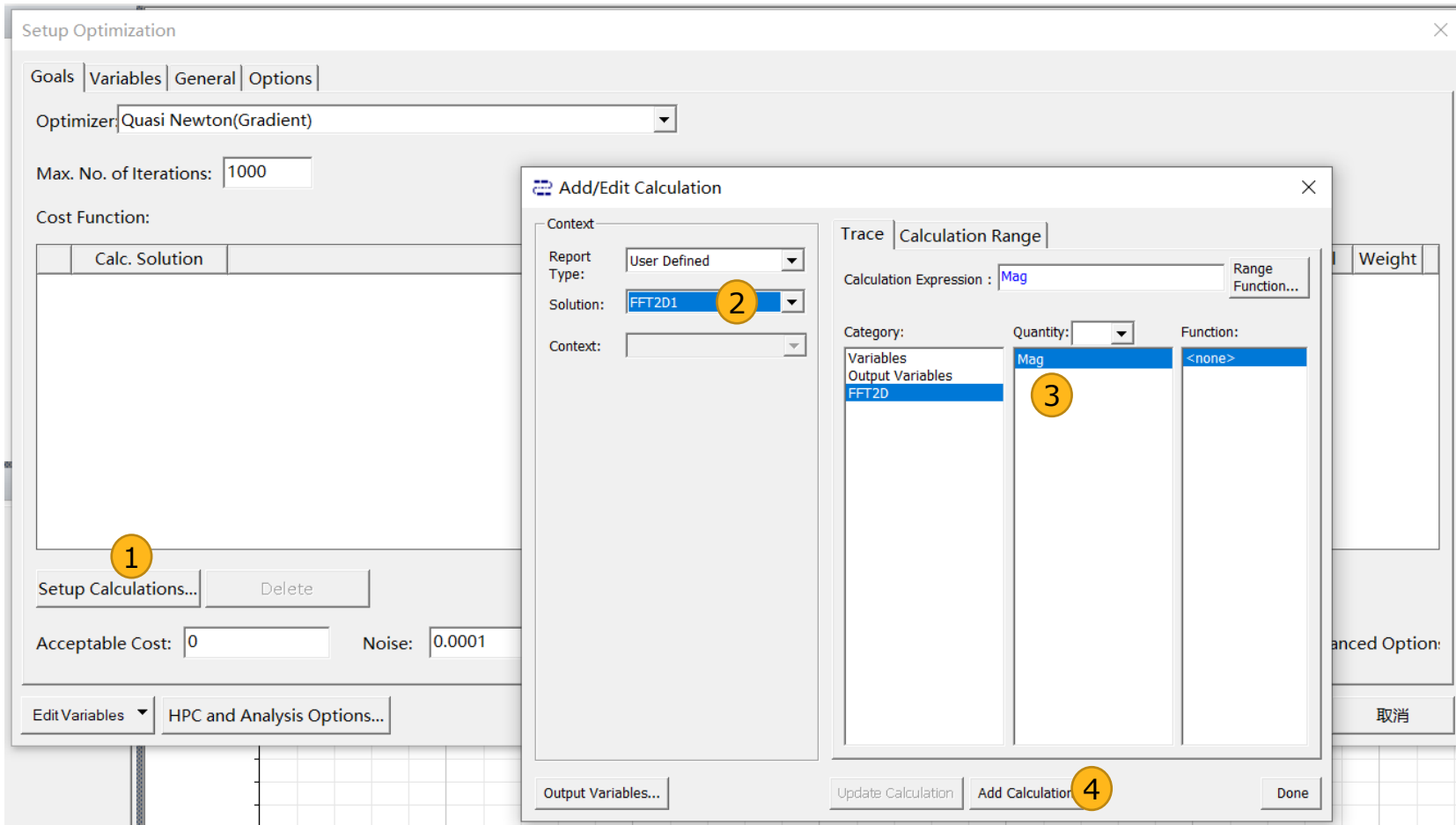
查看FFT2D结果矩阵

```
16 # 定义输出FFT_data的数据类型, 0: 幅值, 1: 复数
17 data_type = 1
```

- 用户可修改脚本17行处data_type的值控制FFT2D的结果为幅值或复数
- 脚本默认输出为幅值

	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE
841	(-503.478	(589.550-	(1855.10+	(153.283+	(-3.08712	(59.8933-	(-580.597	(-138.401	(335813+	(-138.401	(-580.597	(59.8933+	(-3.08712	(153.283-	(1855.10-	(589.550+	(-503.478	(-110.841	(-537.484
431	(-0.60457	(-0.00473	(0.000744	(-0.00048	(0.004969	(-0.00047	(0.000478	(0.001246	(0.173593	(-0.00166	(0.000303	(-0.00083	(0.004791	(-0.00051	(-0.00042	(-0.00529	(-0.60450	(-0.00321	(0.001133
809	(-66.5734	(-240.493	(-78.2741	(-100.910	(-23.6964	(284.112+	(-35.6706	(2.45271+	(-160.794	(50.4965+	(474.774+	(-1.46923	(-11.4353	(52.1025-	(-31.3968	(2.83625-	(209551-	(-311.269	(-176.717
469	(-0.60185	(-0.00391	(0.001691	(-0.00057	(0.003985	(-0.00071	(0.000300	(0.003686	(0.17265+	(-0.00397	(-6.02857	(-0.00184	(0.003381	(-0.00062	(-0.00141	(-0.00543	(-0.60162	(-0.00170	(0.001162
69+	(27600.1+	(-170.823	(167.634-	(113.010-	(47.1828-	(267.514+	(262.822+	(399.641+	(-8.5984+	(8.71827-	(-21.6662	(109.378-	(119.341-	(187.508-	(0.60656-	(-122.608	(-57.0291	(13.3436+	(-577.900
423	(-0.59647	(-0.00363	(0.002162	(-0.00073	(0.002367	(-0.00119	(-0.00031	(0.004766	(0.170742	(-0.00492	(-0.00044	(-0.00319	(0.001194	(-0.00069	(-0.00178	(-0.00544	(-0.59604	(-0.00036	(0.001208
938	(-11.5810	(-413.808	(-4.24764	(-238.394	(51.2122-	(-54.9809	(66.6221-	(478.612-	(-14523.9	(-280.089	(34.9633-	(186.562-	(-32.0163	(108.117-	(49.0009+	(19.6812-	(69.9672-	(160.244+	(75.2056-
286	(-0.58871	(-0.00482	(0.002148	(-0.00081	(0.000775	(-0.00155	(-0.00129	(0.004247	(0.167831	(-0.00443	(-0.00067	(-0.00432	(-0.00099	(-0.00069	(-0.00131	(-0.00566	(-0.58807	(0.000185	(0.001213
56+	(-52.8922	(91.8230-	(-57.2238	(105.186+	(12.2142+	(-8.18970	(-42.5616	(-145.201	(-3.18264	(47.5608-	(93.7980+	(-21.8573	(6.16017-	(6.04532+	(1.29518-	(156.754-	(-1304.14	(-28.8341	(-40.4959
073	(-0.57909	(-0.00775	(0.001829	(-0.00071	(-0.00033	(-0.00161	(-0.00233	(0.002522	(0.163907	(-0.00294	(-0.00060	(-0.00471	(-0.00246	(-0.00068	(-0.00010	(-0.00604	(-0.57828	(-0.00035	(0.001174
372	(-3552.32	(57.7080+	(47.0327-	(1.90513+	(-36.4467	(155.930-	(-51.1189	(188.700+	(30.2142-	(25.1369-	(10.0209+	(115.611-	(-11.5728	(-71.4821	(-19.9193	(-62.1134	(6.19417+	(-100.577	(39.9270-
689	(-0.56834	(-0.01153	(0.001460	(-0.00046	(-0.00085	(-0.00142	(-0.00303	(0.000234	(0.159065	(-0.00109	(-8.79978	(-0.00419	(-0.00283	(-0.00078	(0.001399	(-0.00627	(-0.56746	(-0.00168	(0.001166
87-	(40.0039+	(168.712+	(205.903+	(5.82210+	(-7.97762	(-3.55462	(-18.1776	(96.0316+	(-14865.4	(97.8513-	(8.24124+	(-3.68826	(-36.9055	(-105.681	(-54.2869	(34.6353+	(27.9840+	(-8.00986	(0.269764
521	(-0.55732	(-0.01436	(0.001241	(-0.00019	(-0.00091	(-0.00113	(-0.00301	(-0.00212	(0.153588	(0.000545	(0.000912	(-0.00297	(-0.00215	(-0.00098	(0.002581	(-0.00599	(-0.55639	(-0.00300	(0.001254
009	(68.1339+	(10.5795+	(31.3955-	(19.7971+	(-2.73017	(51.9996+	(-3.13855	(-38.9239	(13.3382-	(81.1551-	(60.8519-	(-11.1939	(-25.7720	(51.9558+	(-7.29140	(81.7742-	(-1994.43	(-114.863	(-5.40079
853	(-0.54680	(-0.01461	(0.001239	(1.16732e	(-0.00068	(-0.00089	(-0.00218	(-0.00429	(0.147949	(0.001454	(0.002273	(-0.00154	(-0.00080	(-0.00111	(0.002898	(-0.00509	(-0.54566	(-0.00350	(0.001394
46-	(-76.5904	(-23.6020	(84.5382-	(-68.6649	(35.2100-	(7.62451-	(99.3560+	(55.1621-	(71.2853+	(-16.2264	(-12.2853	(43.8313+	(10.4300-	(20.6778+	(-1.99402	(-15.5245	(-26.5507	(-64.7960	(-43.1072
355	(-0.53733	(-0.01190	(0.001400	(0.000167	(-0.00019	(-0.00072	(-0.00077	(-0.00595	(0.142709	(0.001156	(0.003673	(-0.00039	(0.000692	(-0.00095	(0.002129	(-0.00372	(-0.53552	(-0.00293	(0.001394
942	(4.48376-	(116.883-	(-22.3939	(41.4510+	(24.5948-	(7.41807-	(97.3698-	(0.859093	(887.884+	(-35.8121	(-18.3671	(-12.2537	(4.21758-	(9.77932+	(3.00778-	(25.5050+	(-45.4304	(-45.5094	(-38.7053
031	(-0.52913	(-0.00747	(0.001611	(0.000375	(0.000571	(-0.00066	(0.000685	(-0.00654	(0.138327	(-0.00064	(0.004669	(0.000131	(0.001843	(-0.00039	(0.000481	(-0.00215	(-0.52597	(-0.00170	(0.001015
82+	(14.1116+	(91.8069-	(21.7435+	(-18.2018	(-14.0784	(-6.43712	(9.76487+	(-75.4844	(10.1581-	(151.682+	(-1.25472	(110.098+	(-20.7526	(27.5870+	(-10.9038	(-17.9317	(-233.933	(-37.2918	(13.5962+

在Maxwell中将FFT2D输出结果作为优化目标



Cost Function:						
	Calc. Solution	Calculation	Calc. Range	Condition	Goal	Weight
	FFT2D1	Mag	Distance(All),Time(All)	Minimize		



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 **ansys**

Thank
You

