

Taming the Ace3P RF simulation package for design work



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Comparing Omega3P with analytical results and HFSS 12.1.2 for a simple "pillbox" geometry

- As a first test, a cylindrical $R_c = 1 \mathrm{m}, l = 1 \mathrm{m}$ geometry was used
- The calculated frequencies and Q-factors for the different modes was compared with results from analytical formulas and HFSS 12.1.2
- TM_{mnp} -modes, analytical Q-factor:

$$Q_{mnp} = rac{I_z \mu_0 \omega R_c \left[\left(rac{m}{x_{mn}}
ight)^2 oldsymbol{\xi}_1 I_{ heta s} + oldsymbol{\xi}_2 I_{ heta c}
ight]}{R_s \left\{ 2 R_c \left[\left(rac{m}{x_{mn}}
ight)^2 oldsymbol{\xi}_1 I_{ heta s} + oldsymbol{\xi}_2 I_{ heta c}
ight] + J'_m{}^2 \left(x_{mn}
ight) I_{ heta c} I_z
ight\}}$$

• The analytical and numerical results match:

Mode name	f, O3P	f, HFSS	f, analytic	Q, 03P	Q, HFSS	Q, ana.		
TM_{010}	1.14742	1.14746	1.14743	80996.62	81045.5	81045		
${ m TE}_{111}$	1.73742	1.73771	1.73742	92066.81	92221.4	-		
${ m TE}_{111}$	1.73742	1.73774	1.73742	92066.75	92219.5	-		
${ m TM_{110}}$	1.82824	1.82846	1.82824	102130.48	102305.0	-		
${f TM_{110}}$	1.82824	1.82856	1.82824	102132.01	102303.0	-		
${ m TM}_{011}$	1.88772	1.88816	1.88772	69156.93	69300.7	69301		
${ m TE}_{211}$	2.09059	2.09137	2.09059	96425.12	969595.1	-		
${ m TE}_{211}$	2.09059	2.09151	2.09059	96426.03	96598.7	-		
$\mathbf{TM_{111}}^{*}$	2.36419	2.36538	2.36418	77599.65	146262.0	-		
$\mathrm{TM}_{111}{}^{*}$	2.36419	2.36543	2.36418	77401.99	82168.9	-		

Frequencies in units of 10° Hz. Modes marked with " is mixed with TE_{011}





What is ACE3P?

- Ace3P (Advanced Computational Electromagnetics 3P) is a suite of finite element solvers capable of calculating several parameters relevant to RF design and diagnostics:
 - Cavity eigenmodes (Omega3P)
 - ► Transient response to beam (Tau3P)
 - Particle tracking with surface physics (Track3P)
 - ► S-parameters (S3P)
 - ▶ Particle-in-cell simulation of beam (Pic3P)
 - ► Multi-physics for integral EM and thermal/mechanical analysis (Temp3P)
- Scalable to thousands of CPU cores, enables handling of large-scale problems
- Uses conformal higher-order tetrahedral elements
- Developed by the Advanced Computations Group (ACD) at SLAC [3]

The challenge with Ace3P: It's user-interface



- Setting up an ACE3P simulation requires many steps
- Many of them manual and error-prone
- Running many simulations produces a lot of files; easy to loose track of differences
- No simple way to compare results between simulations
- Difficult to use for work requiring fast turn-around, such as design and

The mesh used, and field patterns for TM_{010} , TM_{110} , and TE_{211} . Surface color indicating magnetic field magnitude, arrows electric field

Comparing Omega3P and HFSS for a CLIC T24 and TD24 single-cell geometry

What is S_c ?

- Before using Omega3P [1] for RF design, want to make check that results are the same as from HFSS
- Simulating a single cell with periodic boundary conditions
- Comparing key parameters:
 - ► Frequency
 - Q-factor
 - ► R/Q
 - Group velocity
 - ▶ Peak electric field
 - ► Peak magnetic field
 - \blacktriangleright Peak modified Poynting-vector S_c

The modified Poynting vector S_c is a real time-constant vector-field, which gives an indication of likely breakdown sites [2].

This vector field is given as

$$\mathcal{L}_{c} = \mathrm{abs}(\Re(ilde{\mathbf{S}})) + rac{1}{6}\mathrm{abs}(\Im(ilde{\mathbf{S}})) \; .$$

where the absolute value is taken componentwise, and $ilde{m{S}}$ is the complex Poynting vector

 $\tilde{S} = \frac{1}{2}E \times H^*$

Calculation	Frequency	Q-factor	R/Q	v_g	$ \mathbf{E} _{\max}$	$ \mathbf{H} _{\max}$	$ \mathbf{S}_c _{\max}$
T24/M1, P=2	11.99470	6652.48	15978.42	1.7570	2.09390	2.82237	0.401831
T24/M2, P=1	11.98682	6645.12	15947.36	1.7751	2.23270	3.42246	0.599280
T24/M2, P=2	11.99477	6653.70	15978.30	1.8165	2.08956	2.64085	0.395954
T24/3, P=2	11.99477	6653.84	15978.30	1.8170	2.05856	2.64120	0.396020
T24/4, P=2	11.99477	6655.21	15978.18	1.8178	2.04253	2.63874	0.395114
T24/HFSS	11.995	6600.	15956.	1.83	1.95	2.6	0.37
TD24/M1,P=2	11.99472	5532.	14560.79	1.652	2.17452	5.29	0.421
TD24/M2,P=2	11.99484	5541.	14559.71	1.654	2.07334	1.654	0.417
TD24/HFSS	11.9942	5536.	14587.	1.65	1.95	4.1	0.41

• Peak $oldsymbol{E}$ dimensionless, peak $oldsymbol{H}$ and S_c in units of mA/V. Frequency in GHz, R/Q in Ω/m (linac def.), v_q in % of c. Edge lengths in $\mu {
m m}$.

Iris roundoff DWG neck # Elem Mesh

optimisation of RF components

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Making life easier: AcdOpti

- Automates the steps for setting up and running an ACE3P simulation
- Organises the in- and output data
- This enables fast turnaround of simulations, enabling design of RF components
- First goal is to design a tapered damped accelerating structure for a 500 GeV CLIC



Scan a geometry parameter

					ACD project organize	r		
			10 ⁰	20	74			
New		Add geometry instance	Add mesh template	Add parameter sca	an Add meta-analysis			
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		baseline		7 1.23	1e10		 	
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Setup CUBIT scripts



Set parameters for geometry and mesh

				ACD proj	ect organizer		
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New		Add geometry instance	e Add mesh template	Add parameter scan	Add meta-analysis		
Project	t explore	r				Name of runConfig: "runconfig"	
Project	t explore	r TD24				Name of runConfig: "runconfig"	
Project	t explored	r TD24 Geometries		Solver setup nam	e Solver setup type	Name of runConfig: "runconfig"	

Create solver setup and submit, run,

and fetch job at remote cluster

• All peak fields normalised using mean accelerating gradient $\langle E_z \rangle$

		eage length	eage length
T24/M1	41321	400	-
T24/M2	46088	200	-
T24/M3	47646	200	-
T24/M4	73473	100	-
TD24/M1	24364	300	600
TD24/M2	61655	150	300





Plot geometry parameters, mesh parameters, and analysis results against each other over multiple simulations

https://github.com/kyrsjo/AcdOpti

References

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- A. Grudiev, S. Calatroni, and W. Wuench. New local field quantity describing the high gradient limit of accelerating structures. Phys. Rev. ST Accel. Beams, October 2009
- https://slacportal.slac.stanford.edu/sites/ard_public/acd/Pages/Default.aspx

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CERN accelerator school 2011, Chios