COMSOL Modeling of DIII-D Tokamak Systems

COMSOL DAY
Orange County
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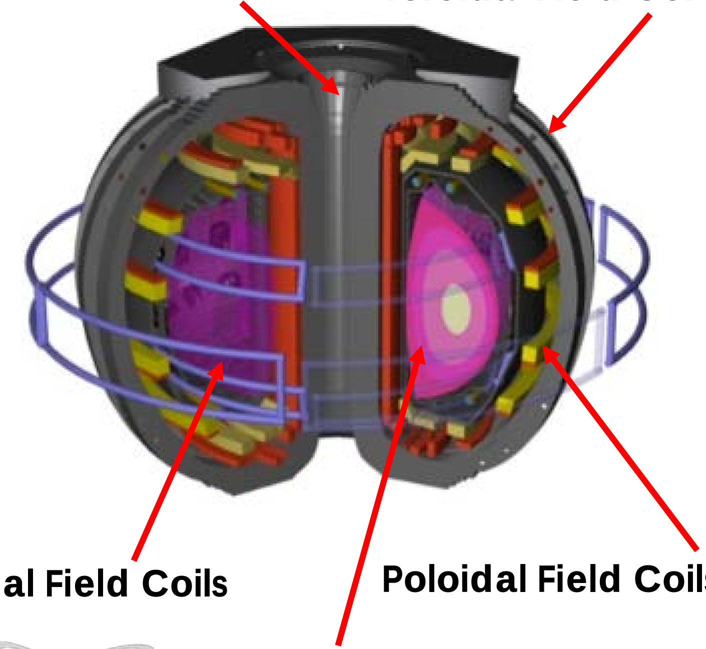
DIII-D NATIONAL FUSION FACILITY

Topics

1. DIII-D Tokamak Description
2. Magnetic Field Interference
3. Plasma Disruption Events
4. Helicon Antenna: Design
5. Helicon Antenna: Test Stand
6. Conclusions & Future Work

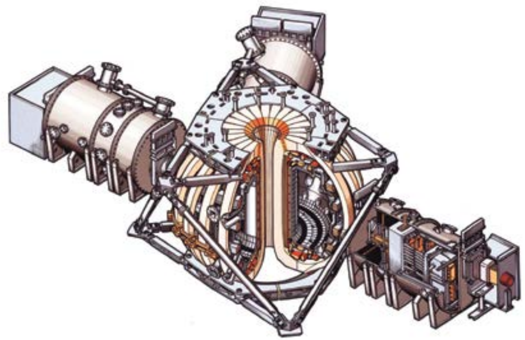
DIII-D Description: Tokamak

Toroidal'naya ***Ka***mera ***Ma***gnitnymi ***K***atushkami



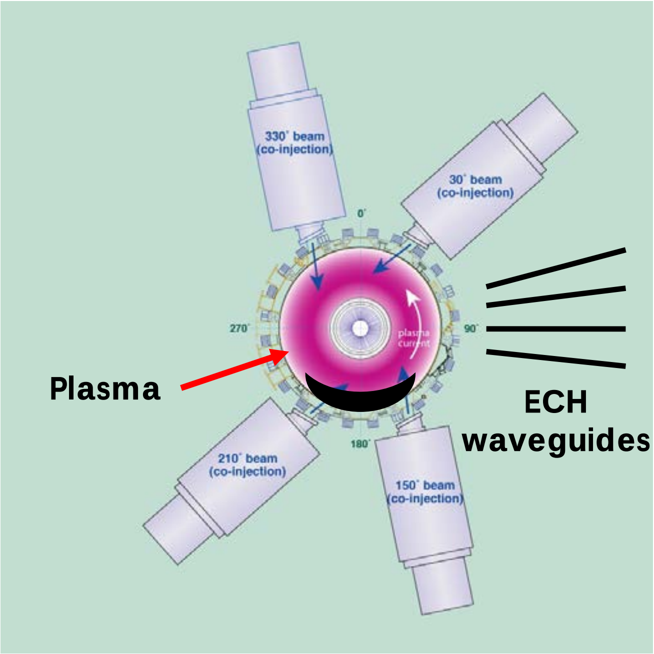
- *Tokamak is a magnetic fusion device consisting of a toroidal chamber with magnetic coils.*
- *Plasma is created and heated up to high temperatures (~10^8 ^{0}C ~ 10 keV) to achieve fusion reactions (Deuterium + Deuterium, Deuterium + Tritium).*
- *Four main types of coils:*
  - **Central Solenoid:** *starts the plasma and provides initial heating (ohmic) to ~1 keV*
  - **Toroidal Field Coils**: *Stabilize the plasma current.*
  - **Poloidal Field Coils**: *Shape the plasma.*
  - **Radial Field Coils**: *Stabilize the plasma.*

DIII-D Description: Heating Systems

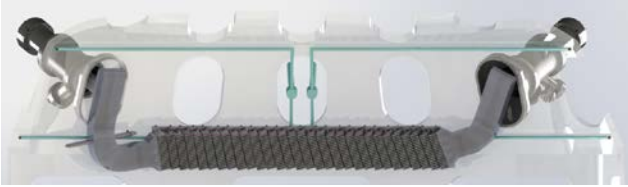


Neutral Beam System
20 MW of power is injected in the form of high energy particles.

Tokamak Top view

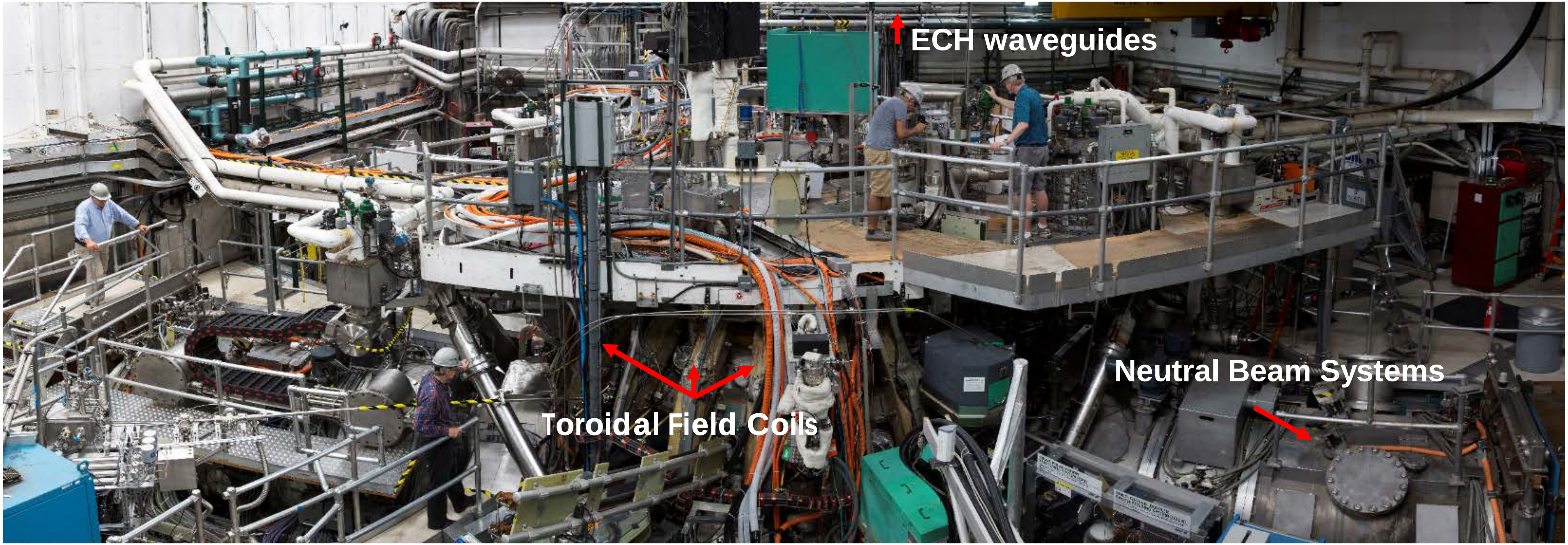


Electron Cyclotron Heating (ECH)
Up to ~4 MW of microwave power is injected to excite electron cyclotron waves at ~100 GHz.



Helicon Antenna *(~ Mar. 2019) will inject 1 MW of power at ~0.5 GHz*

DIII-D tokamak



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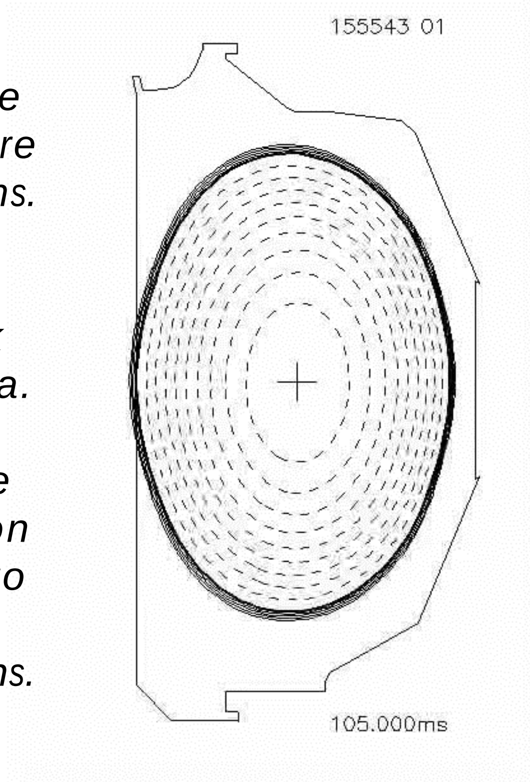
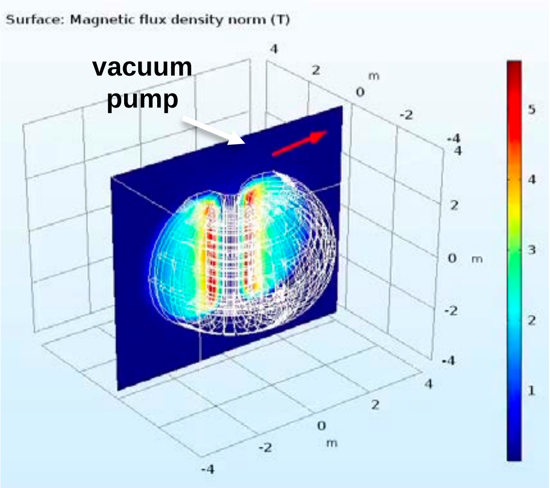
Study #1: Magnetic Field Interference on Systems

- *Static, slow or fast varying magnetic fields can damage vacuum turbo pumps that are vital for main and sub systems.*

- **Magnetic topology** *is well mapped inside the tokamak for fusion studies phenomena.*

- **COMSOL** *is used to calculate the magnetic field distribution outside the tokamak vessel to locate the best location for turbo pumps new installations.*





F_{coils} ~ 10 kA
B_{coil} = 120 kA
I_p = 3 MA

<u>@ x=1.5 & z=3</u>

Bx (G)= 430
By (G)= 0
Bz (G)= 50
B (G)= 437

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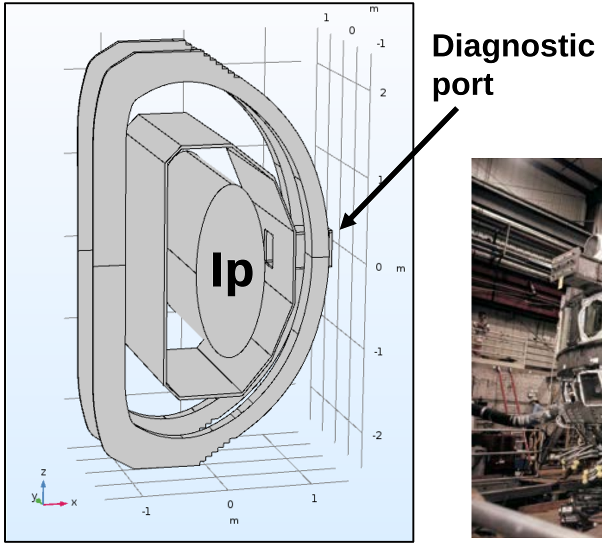
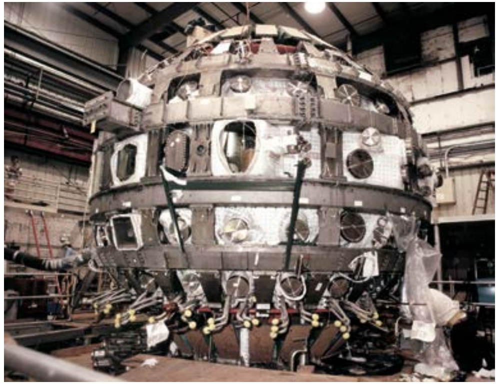
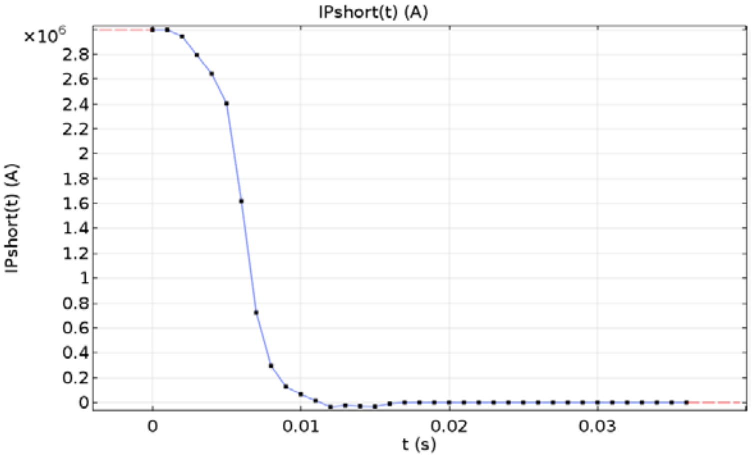
Study #2: Plasma Disruption Modeling (1)

- **Desired behavior:** *Plasma current (~ 2 MA) ramps up and down in a controlled way (~ 0.5 – 2 secs).*
- **Unexpected behavior:** *Plasma current (~ 2 MA) collapses in an instant (~few msec) inducing large currents on the metallic structures that interact with the toroidal magnetic field, producing JxB forces in the 1000 Newton range.*

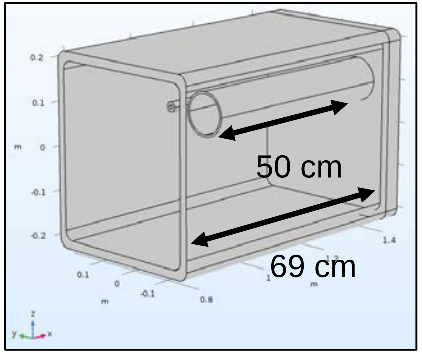


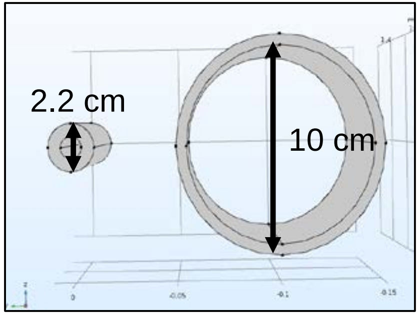
B coil current: 120 kA
Max. disruption Ip: 3 MA



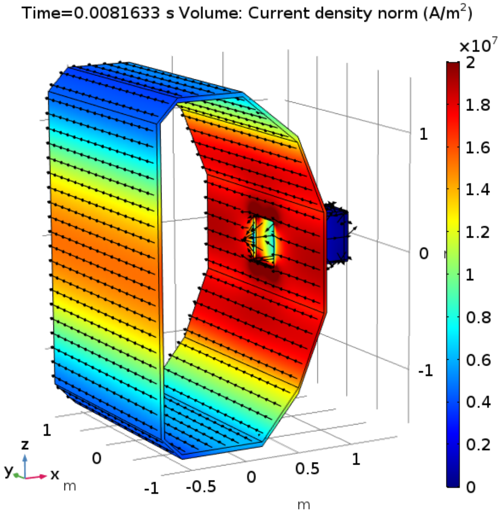


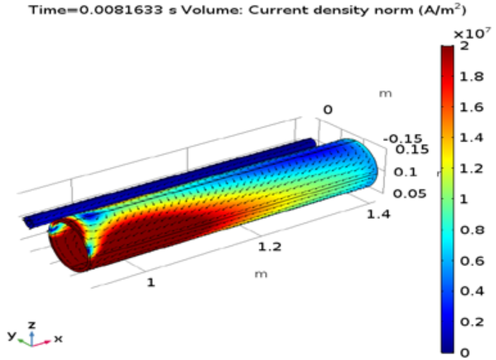
Study #2: Plasma Disruption Modeling (2)

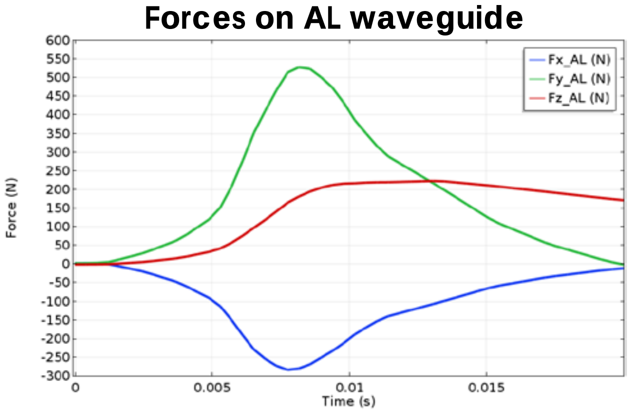


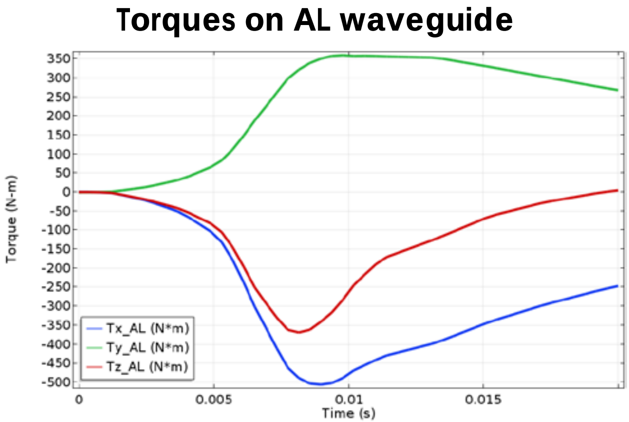


SS (4E6 S/m)   AL (3.7E7 S/m)









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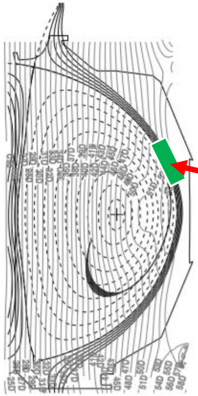
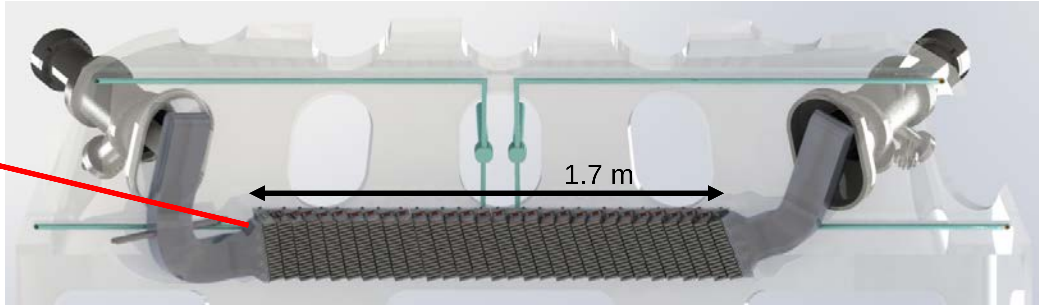
Study #3: Helicon Antenna Project

- **Purpose:** *Inject 1 MW @ 476 MHz to launch a wave toroidally into the plasma for non-inductive current drive.*





- *Power can be injected from either end of the antenna through two striplines.*
- *Striplines are connected directly to the end modules, which then couples power inductively to each of the passive modules in succession.*
- *Antenna will be operated for pulses for up to 10 sec long, every 10-15 minutes.*

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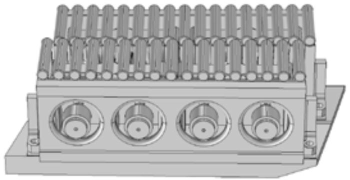
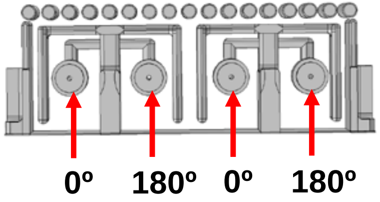
Helicon antenna system must satisfy a number of constraints

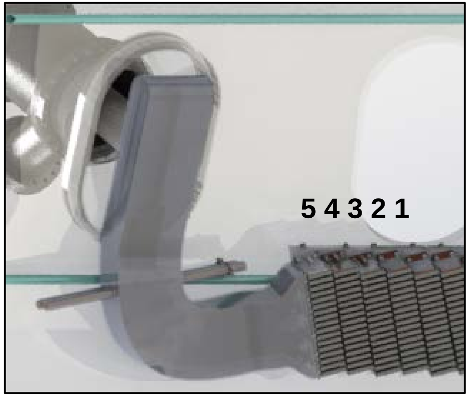
Studies	Module	Stripline
RF		
Thermal		
Electric		

Plasma





Disruption Induced Forces & Torques on Helicon Antenna



Stripline:

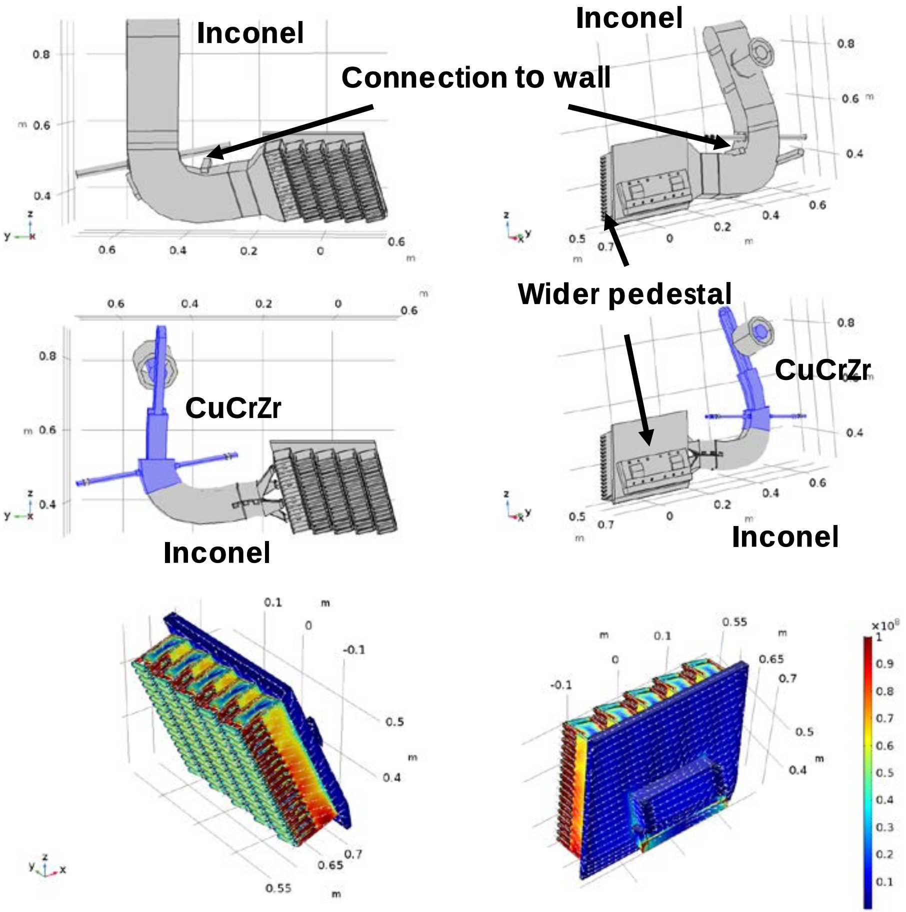
Inner: CuCrZr→CuCrZr/Inconel
Outer: Inconel (7.5E5 S/m)

Modules:

Body: CuCrZr (4.6E7 S/m)
Faraday Shield: Moly (1.8E7 S/m)

Support System:

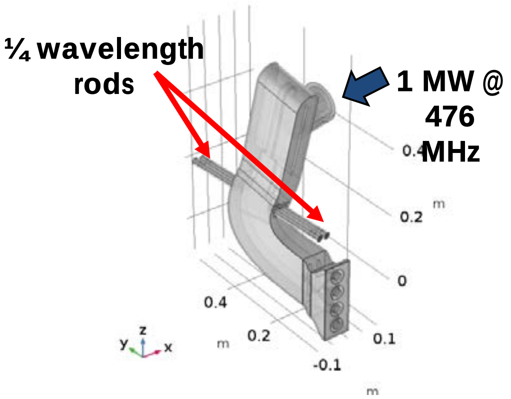
Backplate: Inconel
Pedestal: Inconel

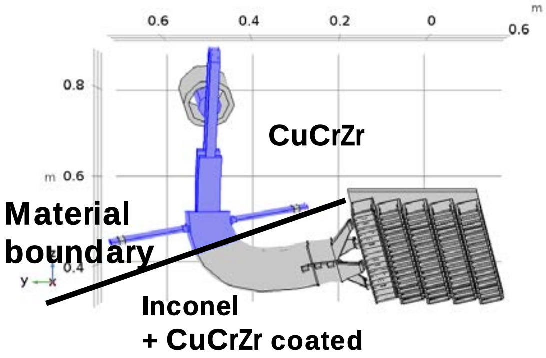


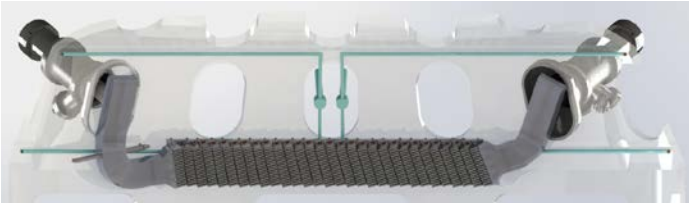
Compare All Inconel and CuCrZr/Inconel Stripline Inner Conductor

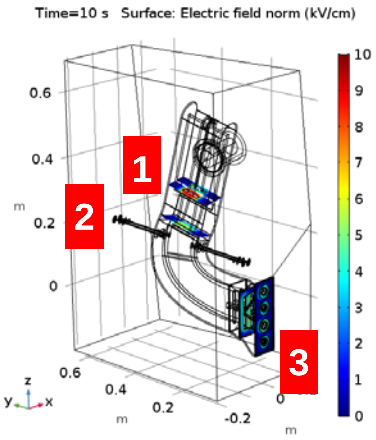
- *Similar Forces & Torques values for pedestal/backplate/modules*
- *SL Inner conductor forces & torques increased by ~ 2x*

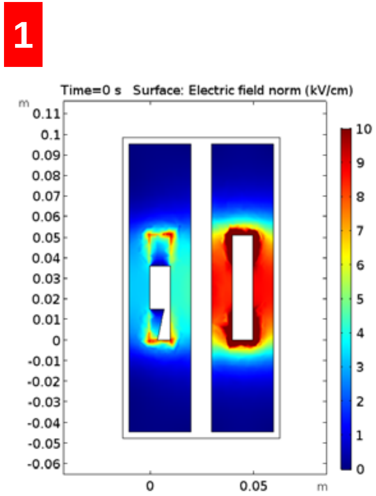
Helicon Antenna Stripline RF Performance

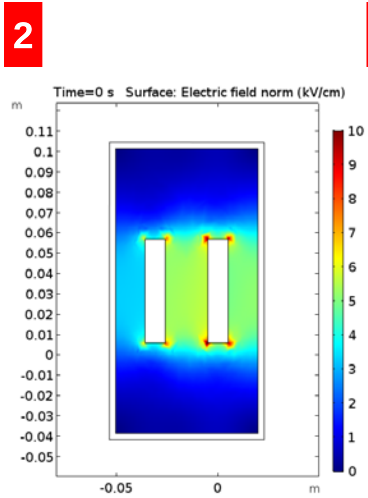


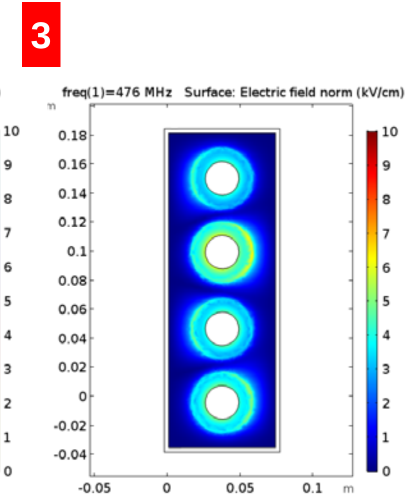




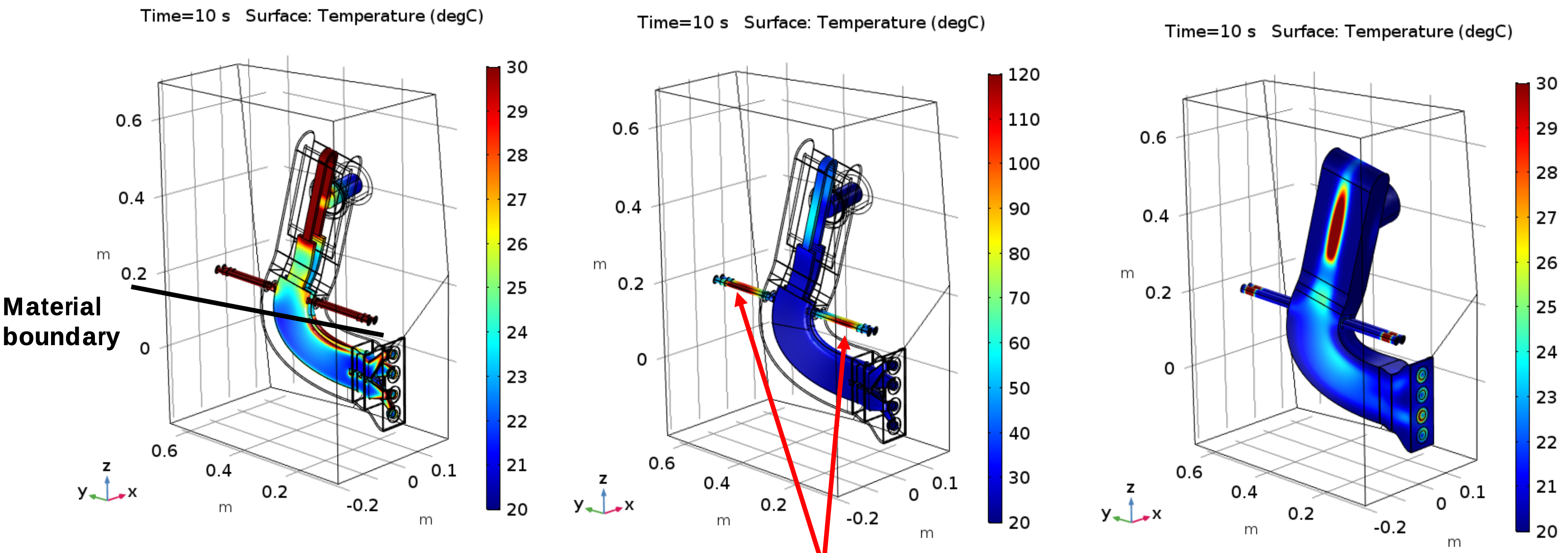








Stripline Temperature below 60 C (1 MW, 10 s)

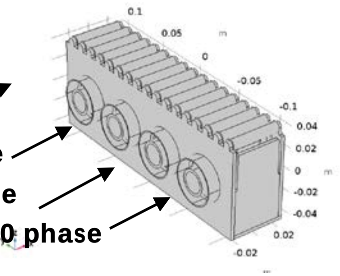


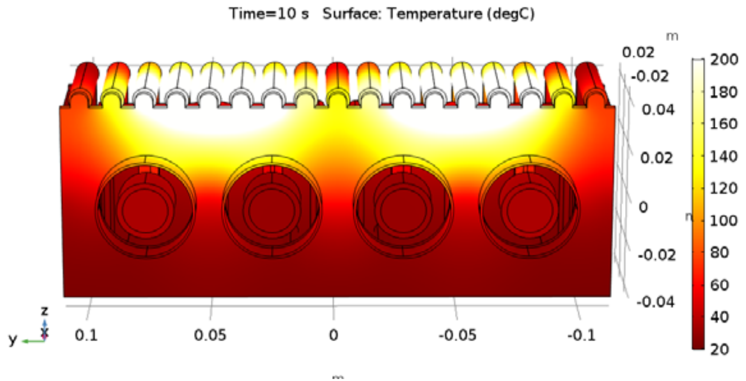
Different scale is used to show hot spots on the ¼ wavelength rods

End module Temperature at 250 C (1 MW, 10s)

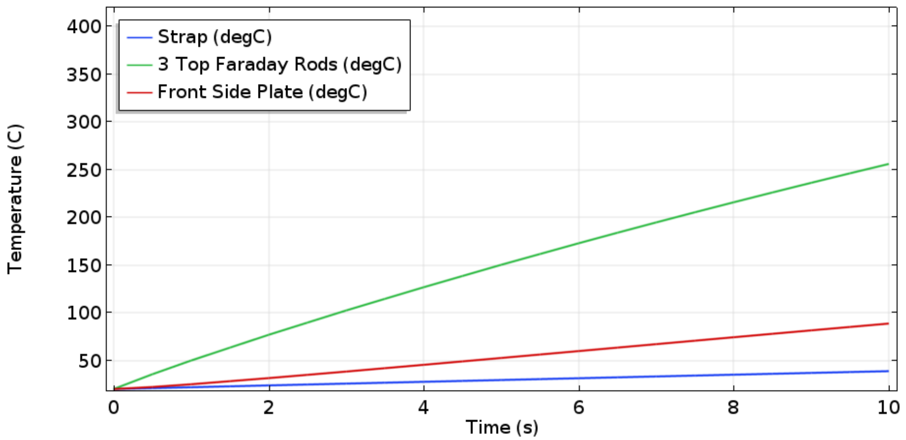
Body: CuCrZr
Faraday Shield: TZM Moly
Ports:30 Ω

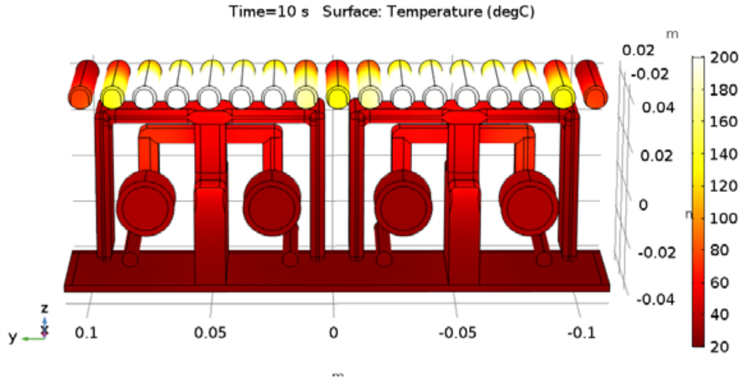
0.25 MW @ 0 phase
0.25 MW @ 180 phase
0.25 MW @ 0 phase
0.25 MW @ 180 phase





Average Temperature over a volume





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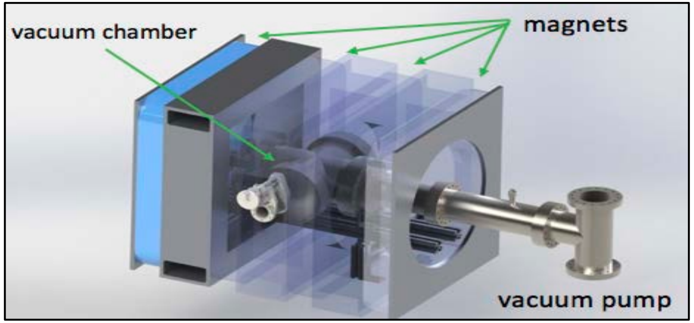
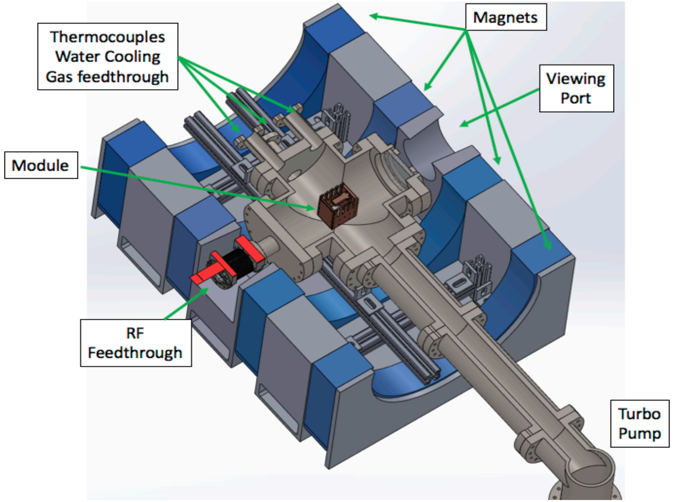
Experiment to Test Antenna Parameters/Conditions

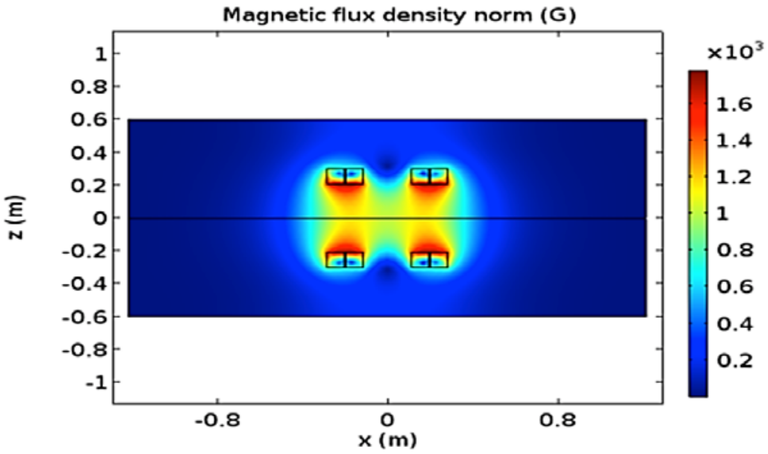
Test scaled down components (module, stripline) before they are built
Operation conditions: 13 kW, 476 MHZ, 0.1 T



3D view: Four coils magnetic system and vacuum chamber



Cross-section view: Test stand systems



Side view: Coils magnetic field

¼ Module design to study RF resonance / E-field effects

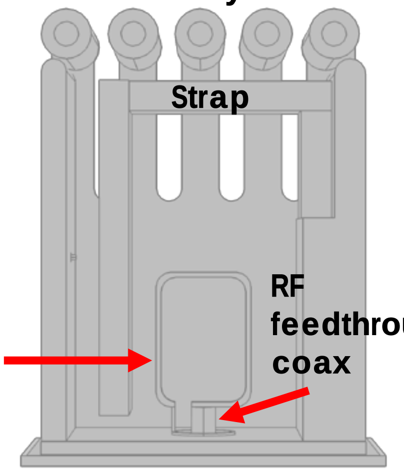
- *13 kW @ ~ 476 MHz*
- *Effects of high electric fields (~ 7 kV/ cm): multipactor, arcs, and glows.*

Faraday shield

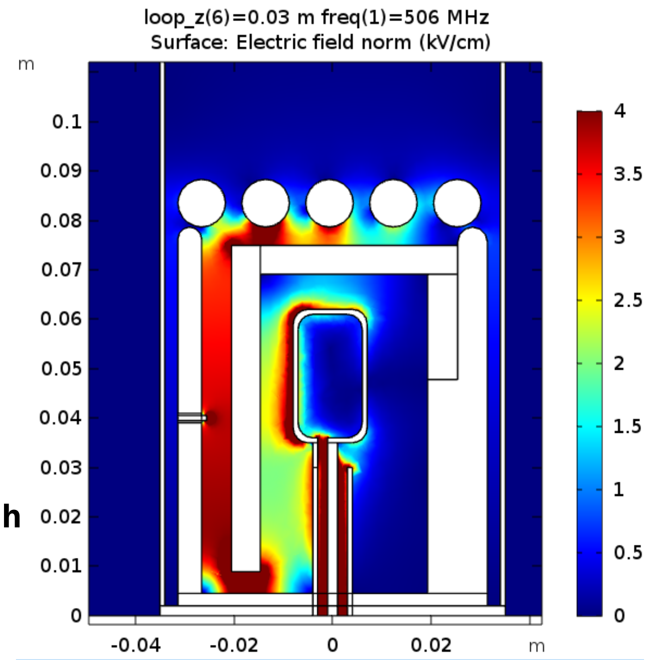
Strap

RF feedthrough loop

¼ module and loop disassembled



Side view: ¼ module geometry



Side view: ¼ module inside E-fields

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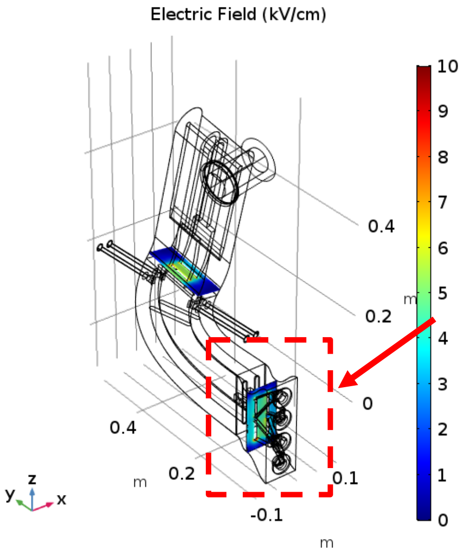
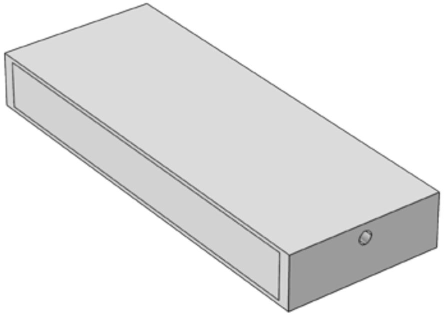
Small Stripline to study E field effects

An RF resonator was designed to replicate **E-field values** *of the stripline and stripline/module connection interface.*

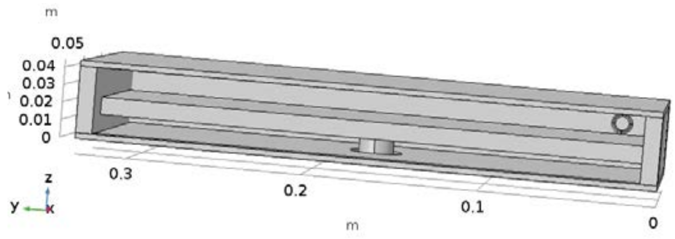


Area of interest

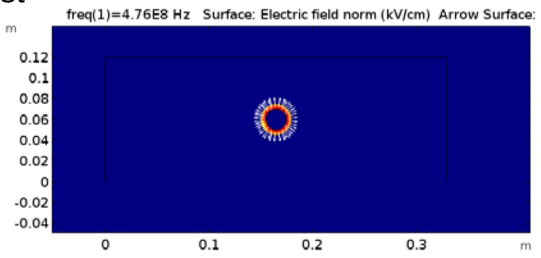
HPHA stripline design



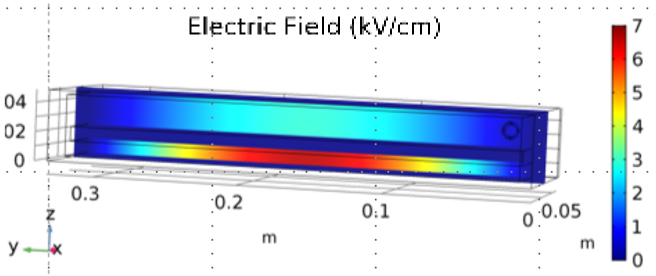
3D view: Test Stripline geometry



Side view: Test Stripline geometry



Bottom View:
E- field Test Stripline/End module interface



Side view: Test stripline inside E-fields

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Conclusions & Future Work

Conclusions

- *COMSOL provides new capabilities to the DIII-D group to accurately design new systems.*
- *Due to more accurate analysis, systems can be pushed to their real limits.*

Future work

- *Disruption analysis for new systems that will be designed and installed in the tokamak.*
- *Revisit operational regimes and limits of installed equipment.*

Clubes de Ciencia – Peru 2017

ITER tokamak reactor: Using coils

Peruvian undergraduates using COMSOL

Thank you

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