Improvements on Impedance Matching and 13 MHz RF System in SNS Ion Source

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RF Ion Source Workshop

Oak Ridge, TN

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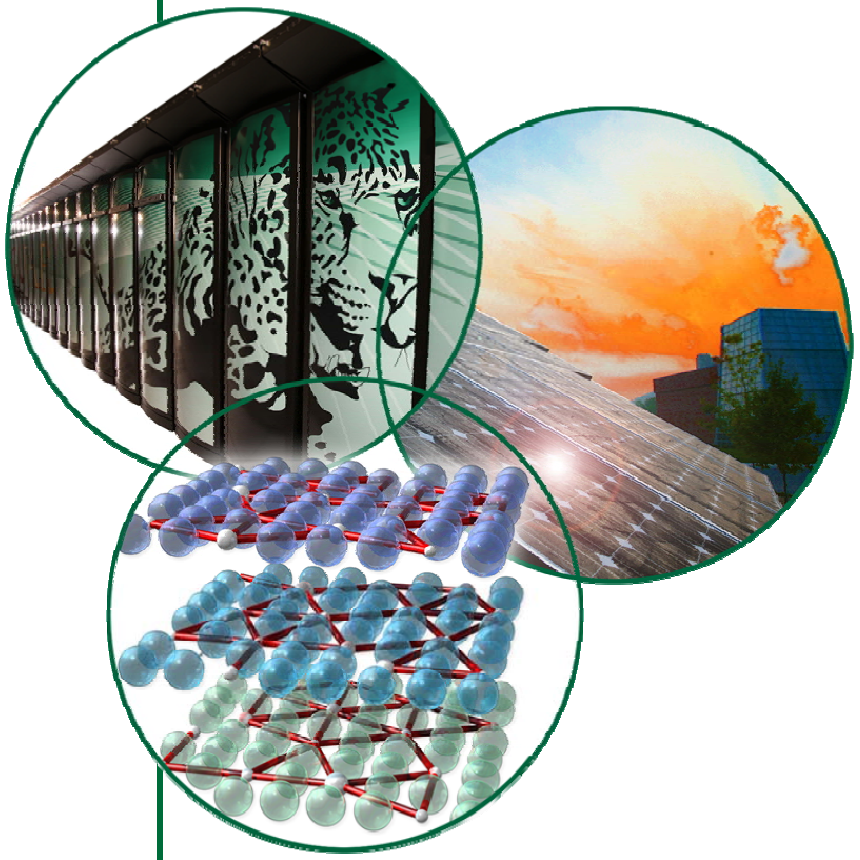

U.S. DEPARTMENT OF ENERGY

OAK RIDGE NATIONAL LABORATORY
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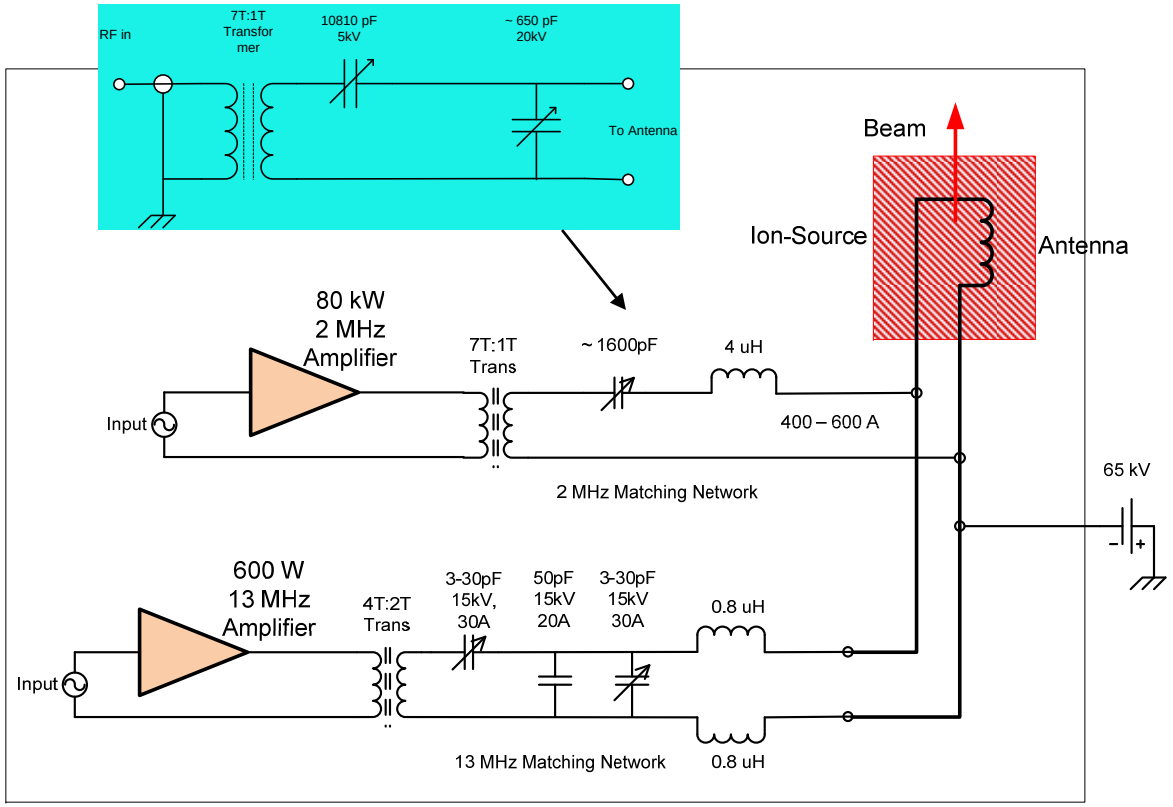
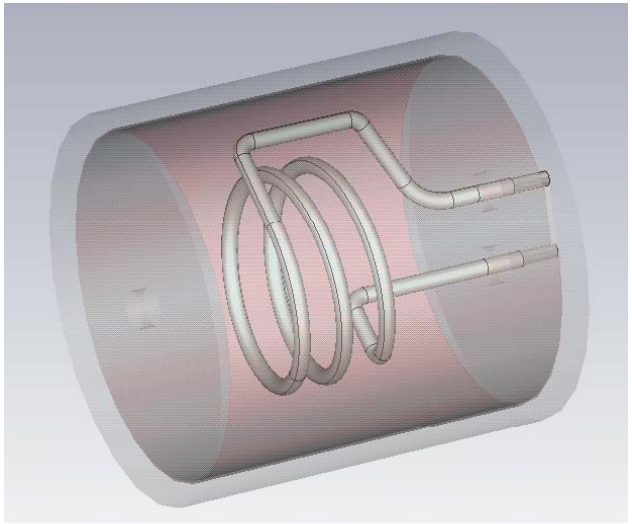
SNS Ion Source RF Z Matching
(with Present Internal Antenna Design)

- Present system
  - Both 2 MHz and 13.56 MHz amplifiers are combined through impedance matching networks to deliver RF power to the Ion-source antenna
  - Main RF power from 2 MHz 80 kW pulsed amplifier at 6% duty cycle
  - Plasma igniter system uses 13.56 MHz CW amplifier (~600 W max)
- Existing matching networks for internal antenna design
  - 2 MHz matching uses only one variable element (vacuum capacitor) at the matching transformer output that cannot provide perfect good matching
  - A series inductor is used to the antenna to raise the input inductance that can use a smaller capacitance
  - 13 MHz matching is done properly with two variable capacitors
  - Matching network with 2 capacitors to be tested

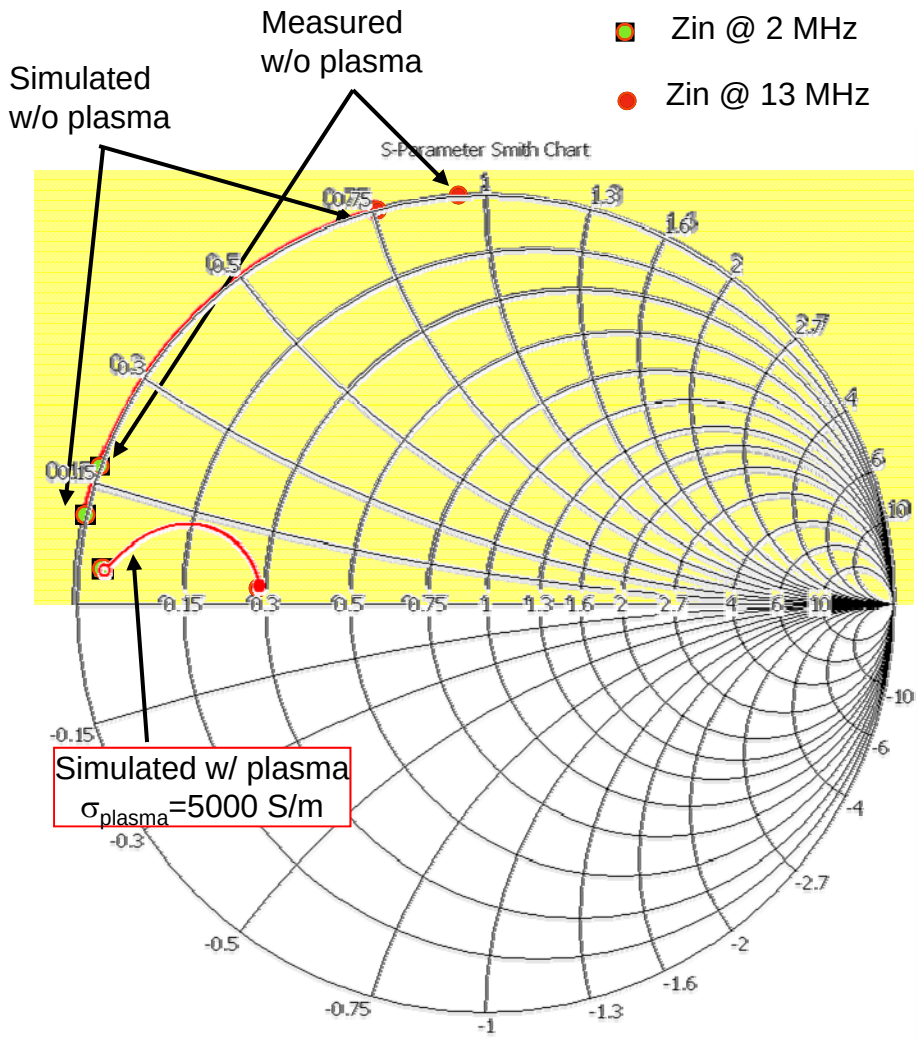


RF Modeling of Ion Source (Internal Antenna)



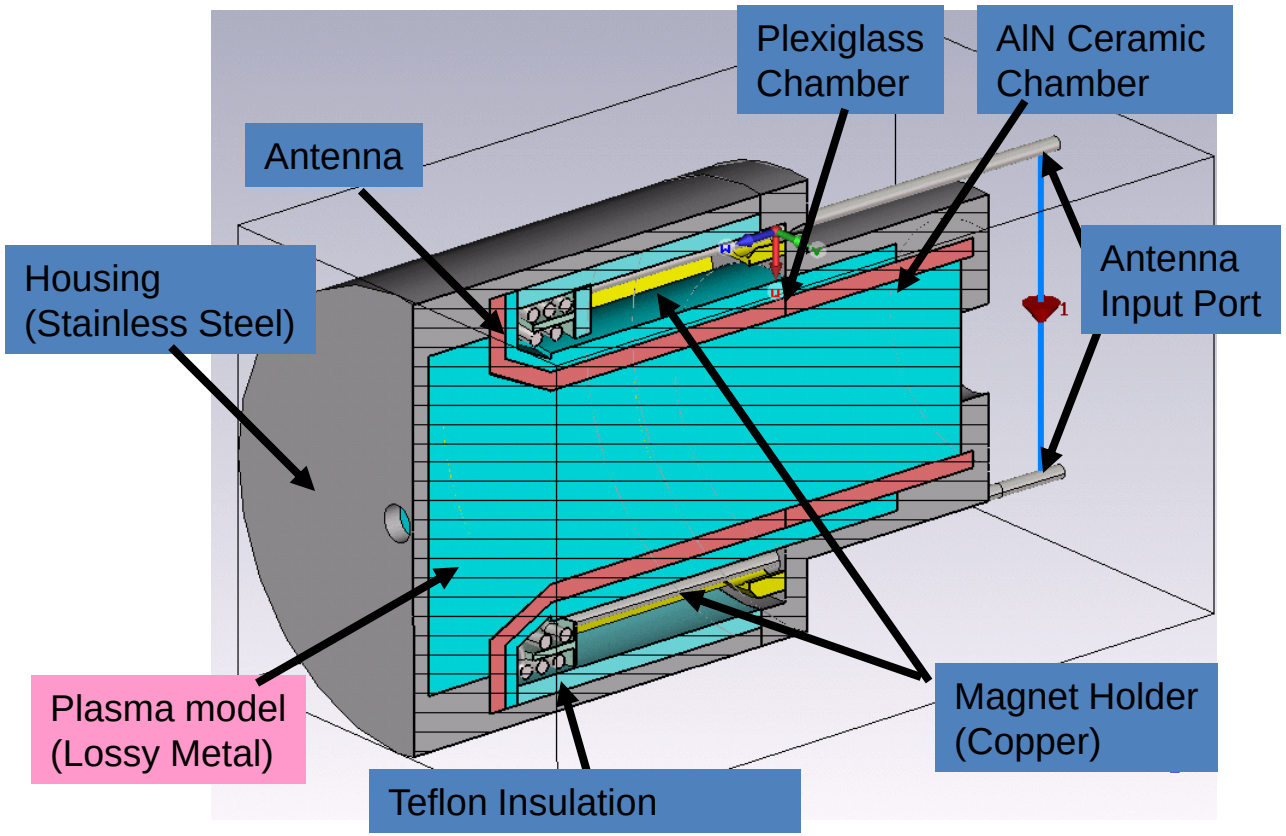
- CST MWS package used for simulation and analysis of the ion source RF
  - The actual antenna impedance can be estimated with the element values in the matching network
  - An equivalent conductivity σ for modeling plasma in MWS for a design can be found for the antenna input resistance (the data provided in Y. P. Raizer[1] can provide rough estimate of σ)
  - Simulation is done with 20 mils thick alumina ceramic insulated internal antenna ion source
  - The simulation may be used to find other RF parameters for design improvement

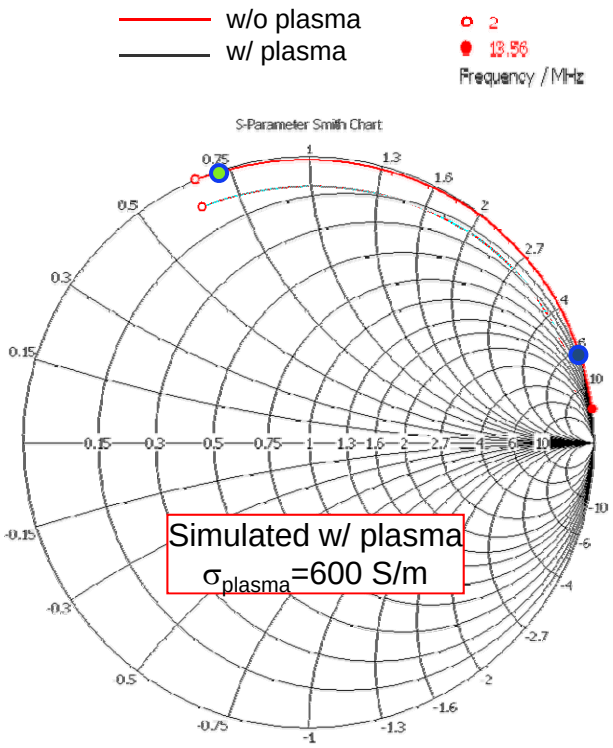
[1] Y. P. Raizer, Gas Discharge Physics



Simulated and measured antenna input impedances

RF Modeling of the Ion Source (external antenna)





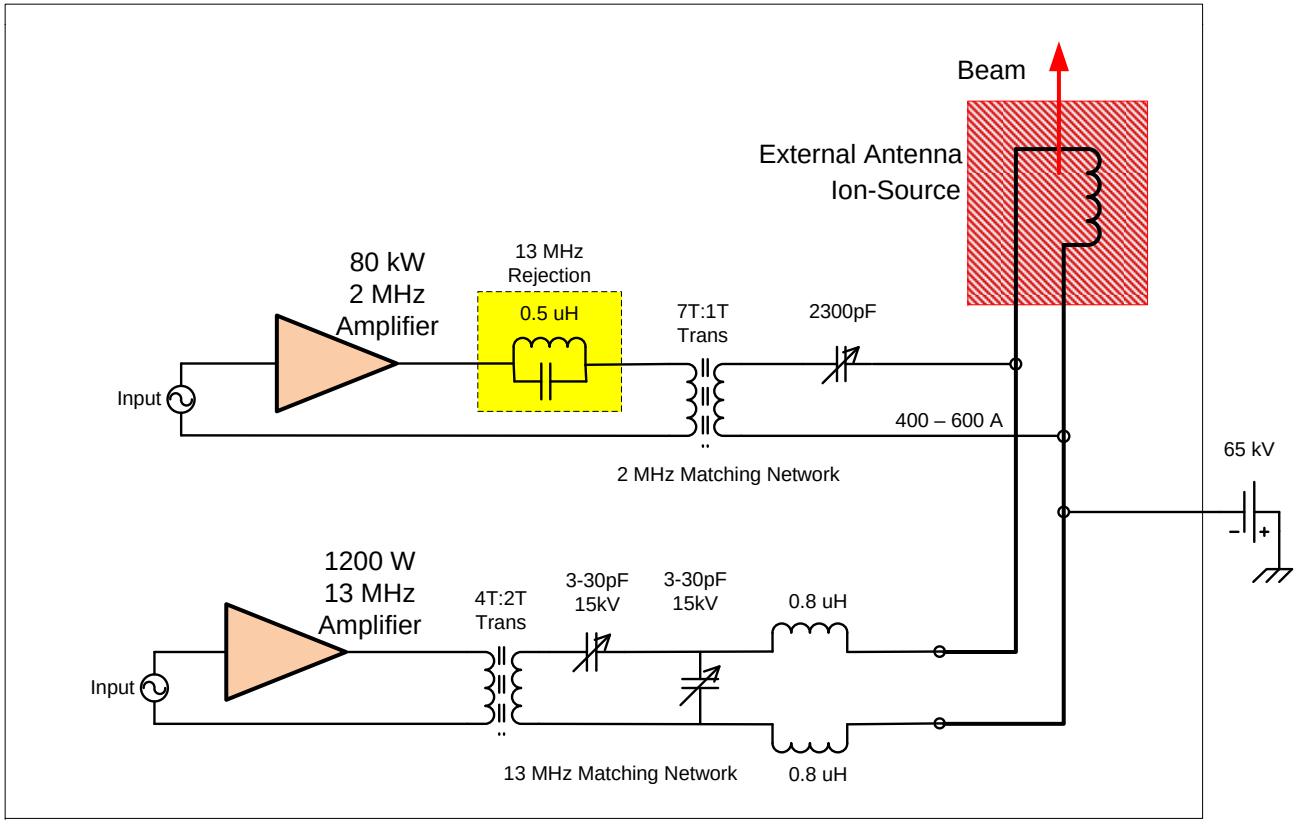
Antenna impedance Zin measured w/o plasma
2 MHz, 13.56 MHz

- External antenna ion source is also simulated and analyzed to
  - Minimize antenna voltage breakdown
  - Analyze with high permeability ferrite material for enhance beam output current
  - Minimize the magnet holder heat loading
- The conductivity σ may need to be determined for each chamber geometry

SNS Ion Source Z Matching
(External Antenna Design)

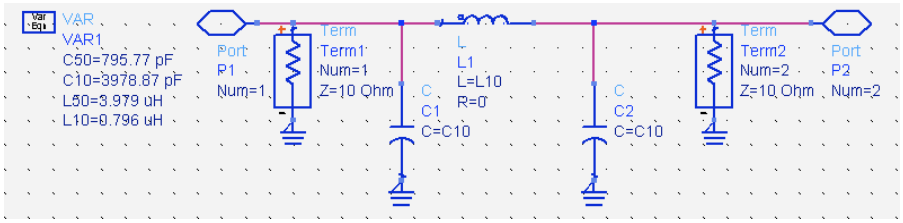
- Test of the external antenna ion source has been successful
  - The 4 uH inductor was removed since the external antenna has higher inductance in 2 MHz antenna system (3 uH vs. 0.7 uH)
  - 13 MHz rejection trap was added (full low pass filter is being built)
  - 13 MHz matching network was modified

- Future Improvement of Z Matching
  - If a separate antenna is used for 13 MHz, mutual coupling will be negligible
  - Two element capacitive matching network can be used in 2 MHz after testing
  - Frequency hopping technique for ignition and operation during pulse only with 2 MHz



LPF Examples (13 MHz blocking)

3-pole Butterworth

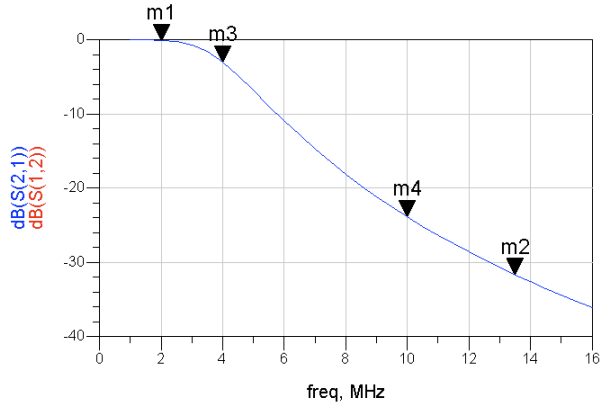


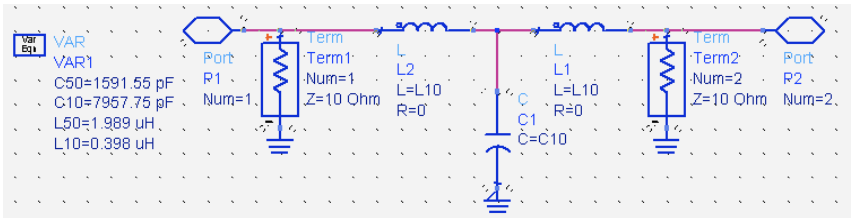
m1
freq=2.000MHz
dB(S(1,2))=-0.068

m3
freq=4.000MHz
dB(S(1,2))=-3.013

m4
freq=10.00MHz
dB(S(1,2))=-23.897

m2
freq=13.50MHz
dB(S(1,2))=-31.702



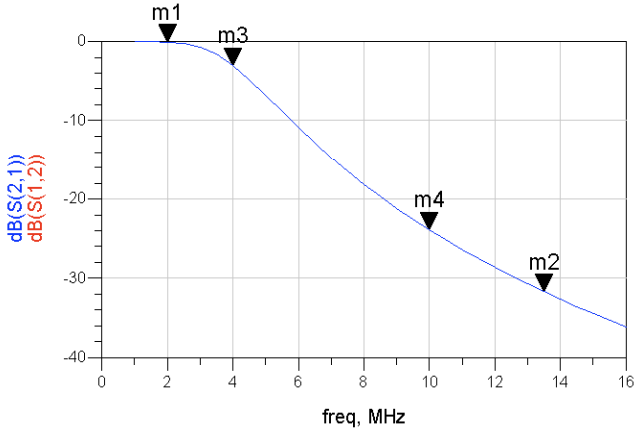


m1
freq=2.000MHz
dB(S(1,2))=-0.067

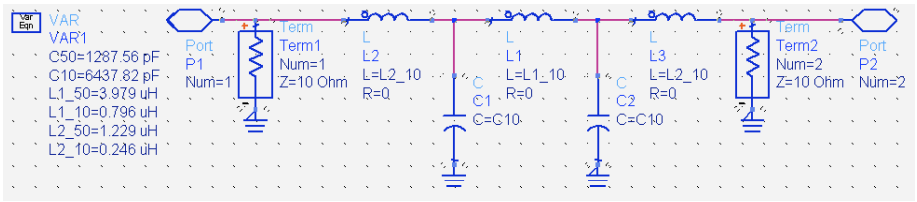
m3
freq=4.000MHz
dB(S(1,2))=-3.012

m4
freq=10.00MHz
dB(S(1,2))=-23.899

m2
freq=13.50MHz
dB(S(1,2))=-31.704



5-pole Butterworth

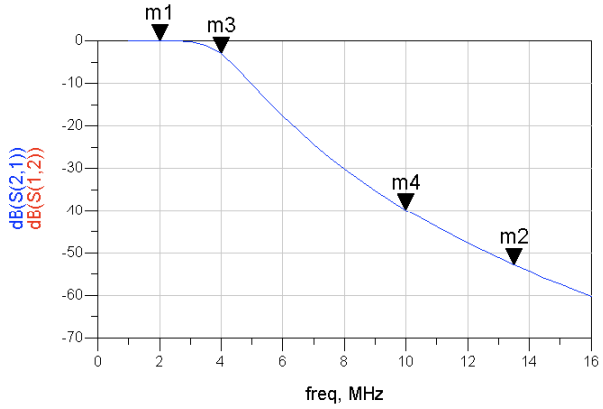


m1
freq=2.000MHz
dB(S(1,2))=-0.004

m3
freq=4.000MHz
dB(S(1,2))=-3.012

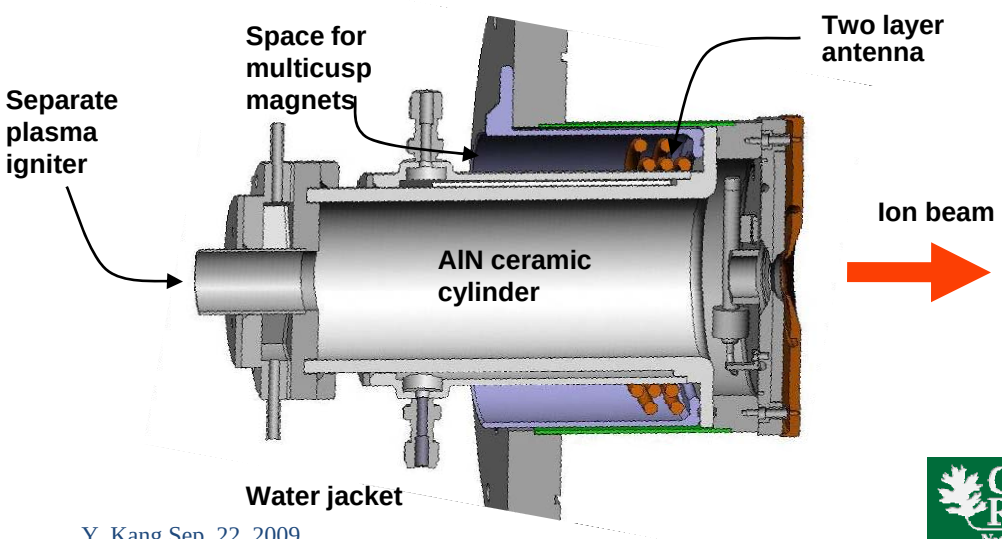
m4
freq=10.00MHz
dB(S(1,2))=-39.802

m2
freq=13.50MHz
dB(S(1,2))=-52.835

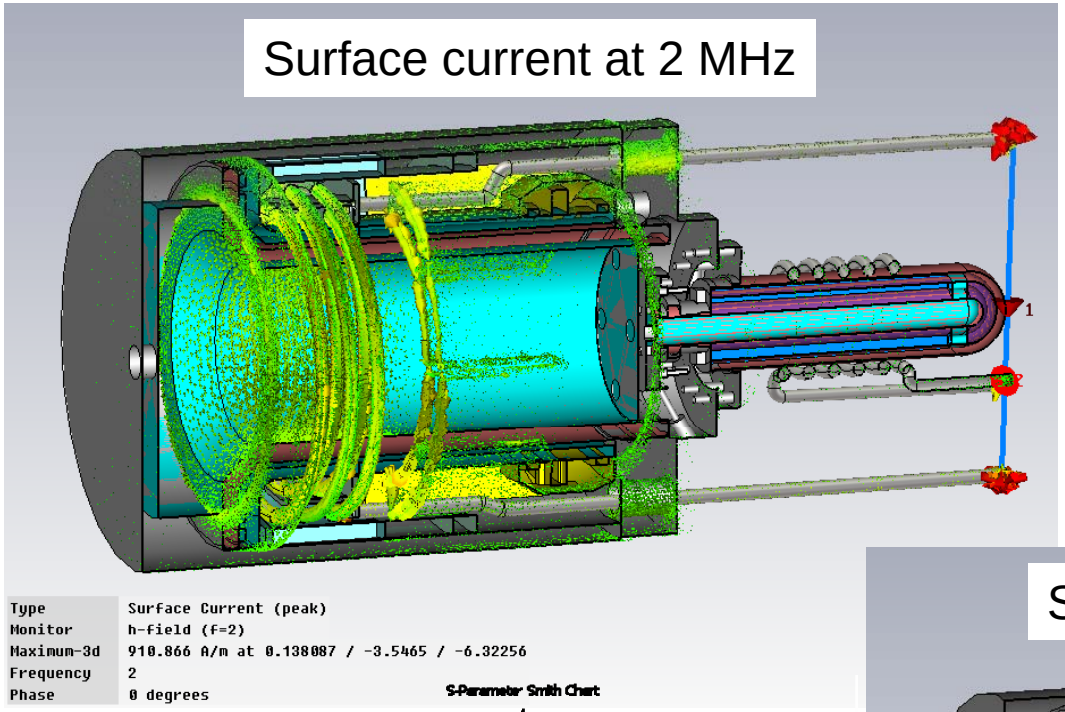


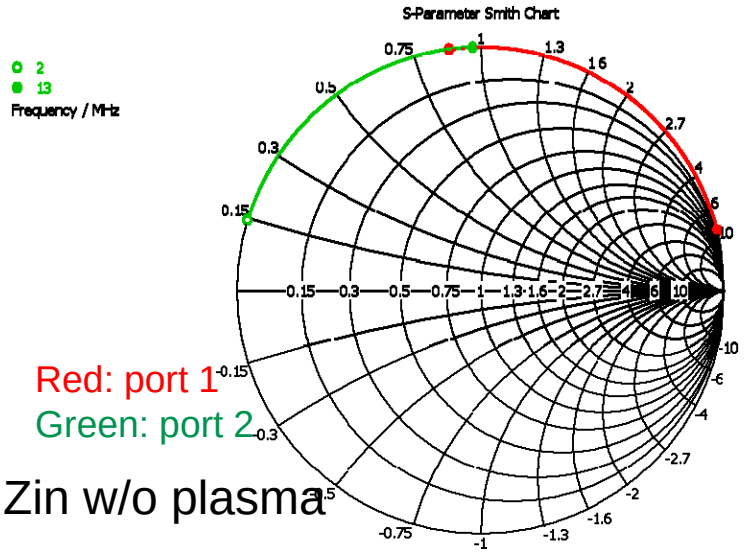
Plasma Igniter Development

- Reliable plasma ignition remains as a major problem with one antenna system
- DC P- gun was developed and used but has electrode erosion problem
- Plasma RF gun with a separate 13.56 MHz antenna is to be tested
  - Greater isolation of the two power amplifiers and easier RF impedance matching
  - A small diameter ceramic chamber behind the main plasma chamber
  - Lower power 13 MHz operation and extending the life of the ion-source chamber/antenna
- Frequency hopping technique between ignition and operation to be developed for using 2 MHz main RF amplifier for the ignition
  - RF frequencies are switched and elements in the impedance matching network is also varied accordingly



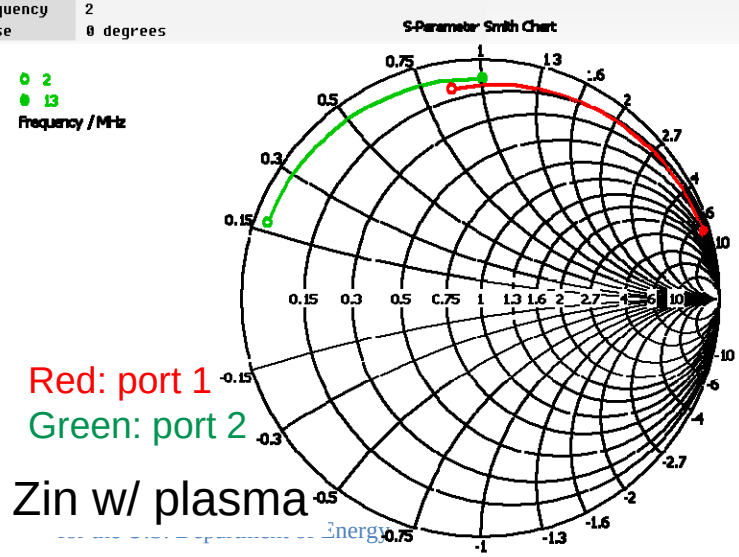
Ion Source with Two Antennas





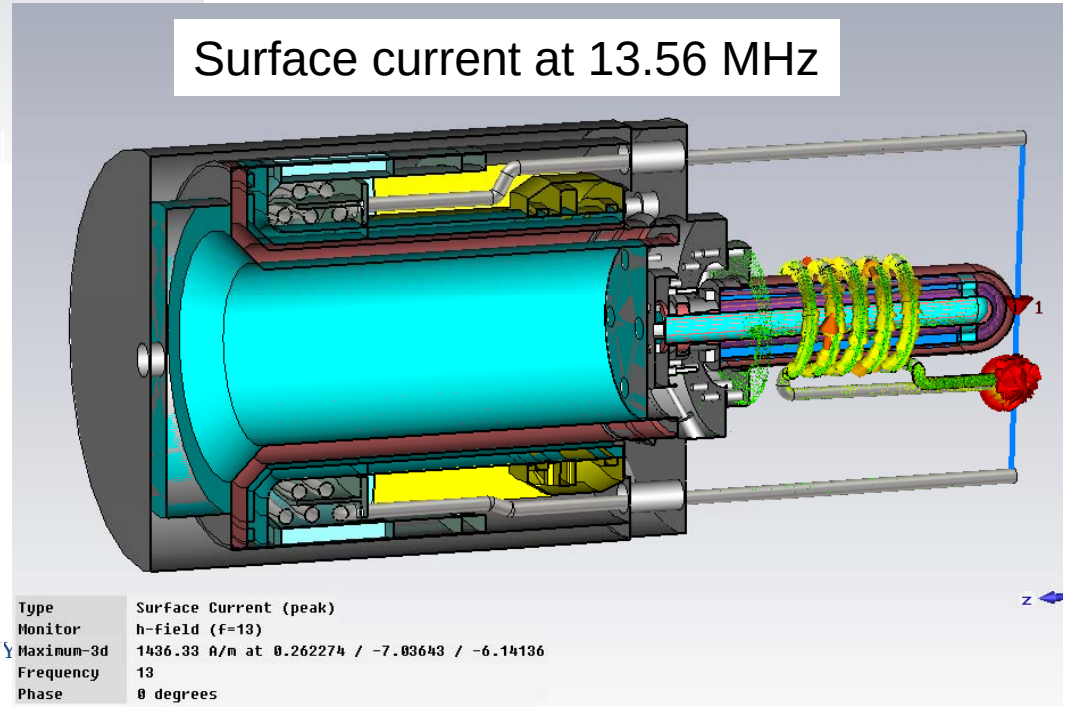
Red: port 1
Green: port 2

Zin w/o plasma



Red: port 1
Green: port 2

Zin w/ plasma



Summary

- Internal antenna ion source Z matching
  - One element impedance matching was employed using a variable capacitor with a series inductor to raise the antenna input inductance for lower tuning capacitance
  - Two variable capacitor matching is used in 13 MHz system
  - 600 W maximum 13 MHz amplifier was sufficient for the 13 MHz ignition
- External antenna ion source Z matching
  - Successfully tested with higher H^- ion beam current up to 42 mA with longer antenna lifetime
  - 1200 W maximum 13 MHz amplifier was used for the testing
  - The series inductor was removed to use the same variable capacitor (this improves the efficiency slightly)
- RF simulations can help the ion-source Z matcher designs and other optimization
  - Plasma equivalent conductance σ for simulation can be found by comparing to the matching network element values
  - This σ can be useful to predict other ion source RF properties
- Improvement on the impedance matching and plasma igniter development
  - Removal of the series inductor required additional 13 MHz rejection at the 2 MHz input
  - 2 antenna system that has good isolation and possibly low power 13 MHz to be tested
  - 2 MHz impedance matching network using two variable capacitors to be tested
  - Technique of frequency hopping between ignition and operation during a pulse using only the 2 MHz amplifier to be developed