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High Duty Factor RF H- Ion Source

NIBS-2020

Development of External RF Antenna based Cusp Free High Duty Factor Pulsed Negative Hydrogen Ion Source

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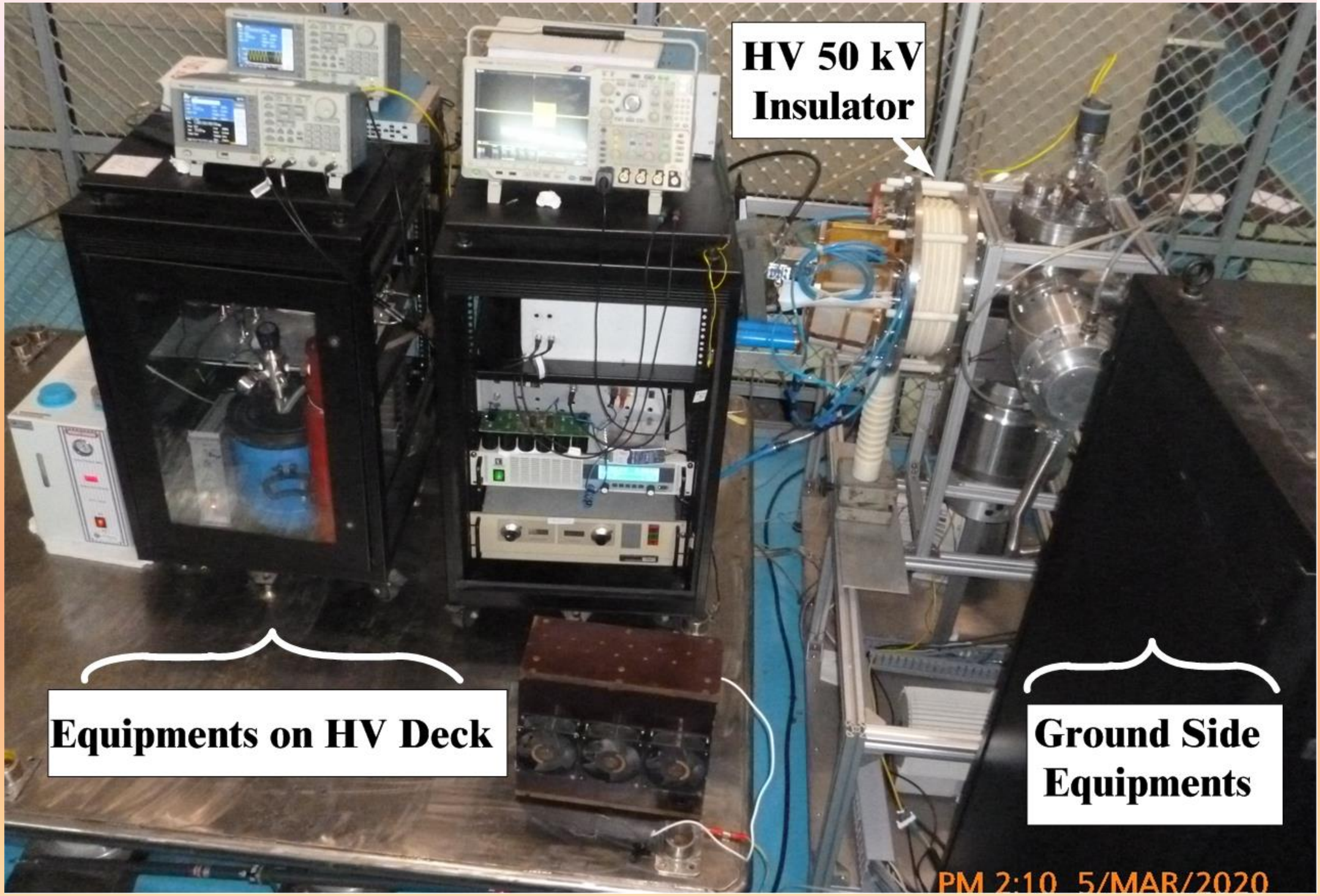
High Duty Factor RF H- Ion Source Setup

High Duty Factor RF H- Ion Source



Main heat generating components are water cooled and other electronic components are forced air cooled for high duty factor operation

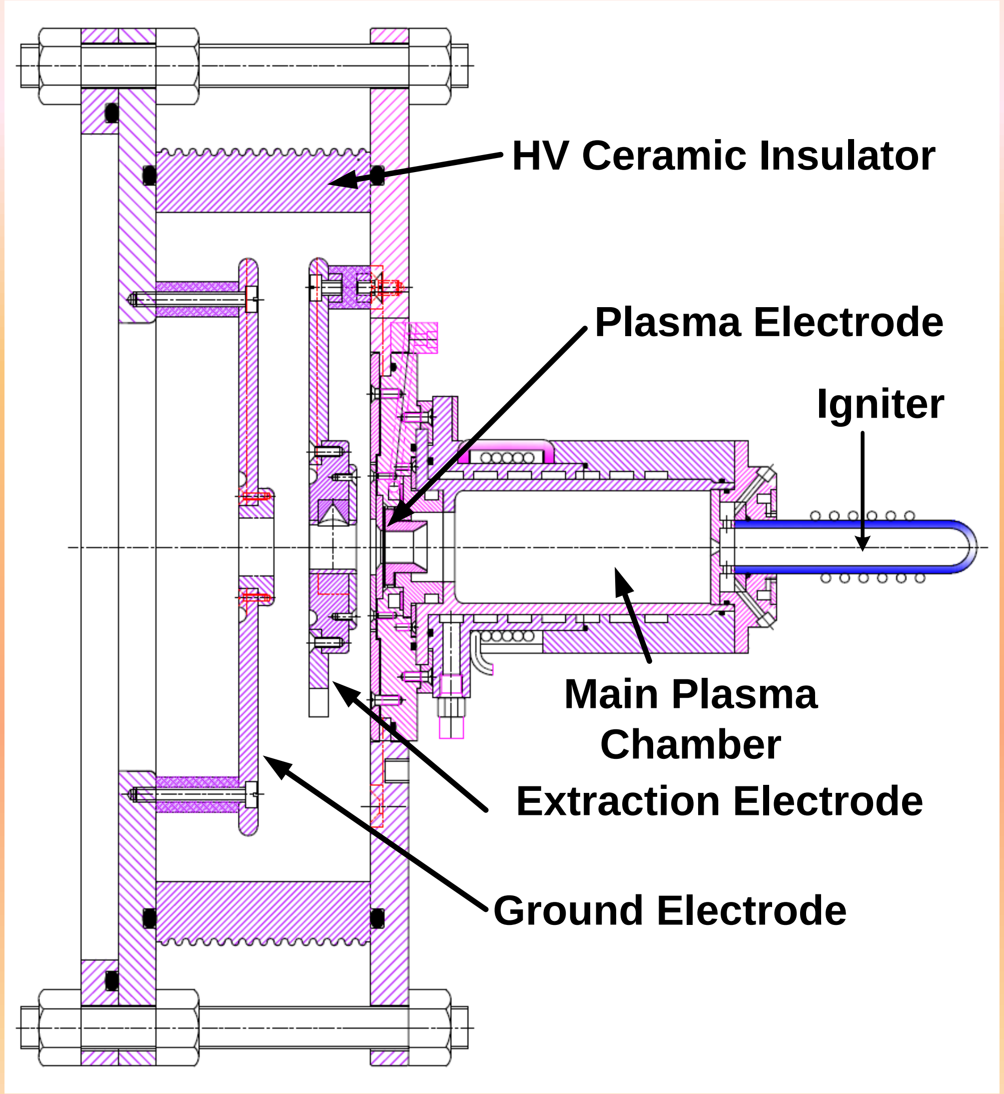
Measured Parameters of Ion Source

High Duty Factor RF H- Ion Source Measured Parameters

Description	Parameters
Type	RF based Ion Source
Particles	H-
Beam Energy	50 keV
Beam Current	11 mA
Main Plasma Chamber Frequency	2 MHz
Igniter Frequency	13.56 MHz
Pulse Width	2 ms
Pulse Repetation Rate	50 Hz
Duty Factor	10%

RF Ion Source Assembly

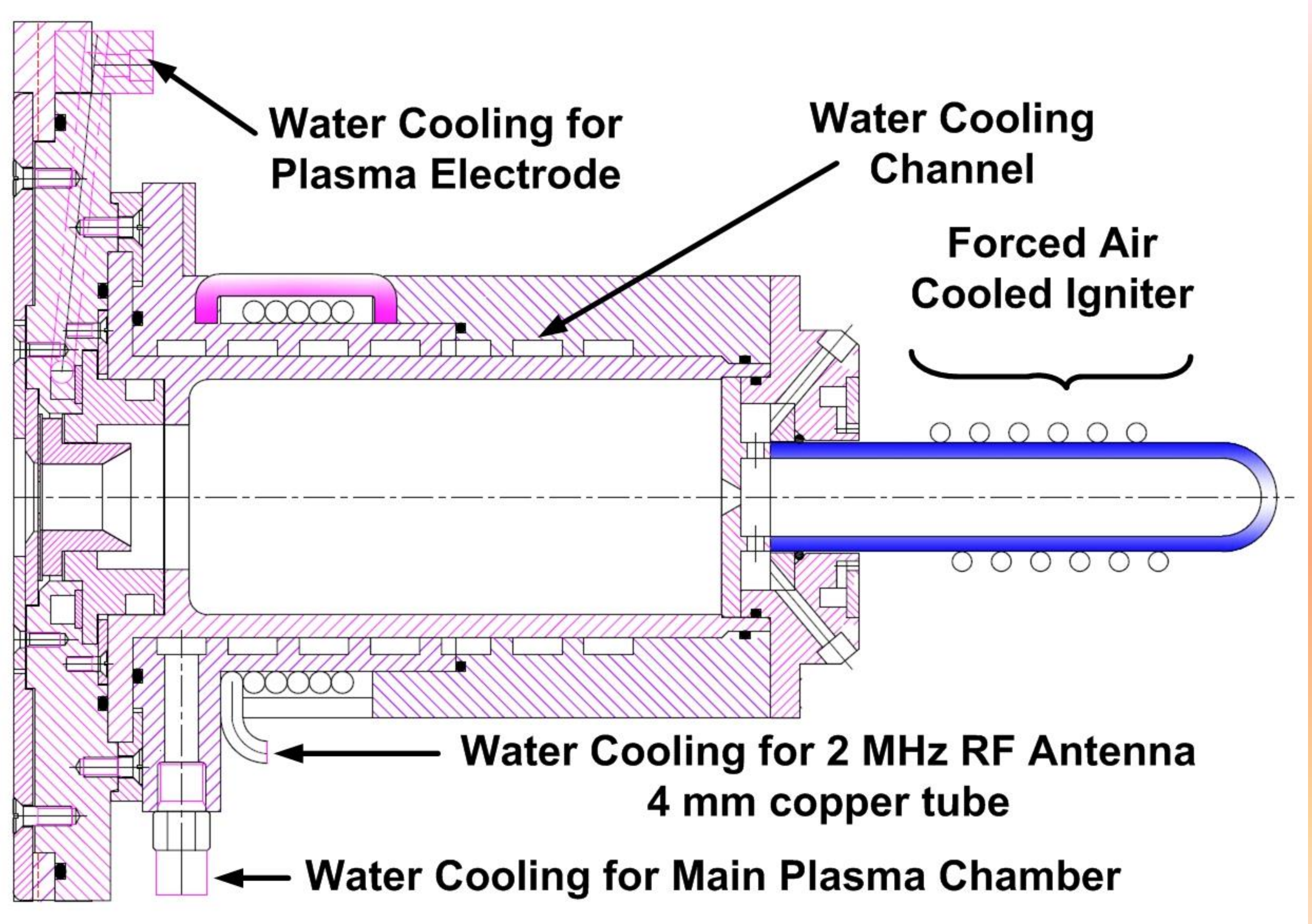
RF Ion Source Assembly



2D-CAD drawing of Hydrogen Plasma Generator and Three Electrodes

Plasma Chamber, Plasma Electrode, 2 MHz RF Antenna and Igniter

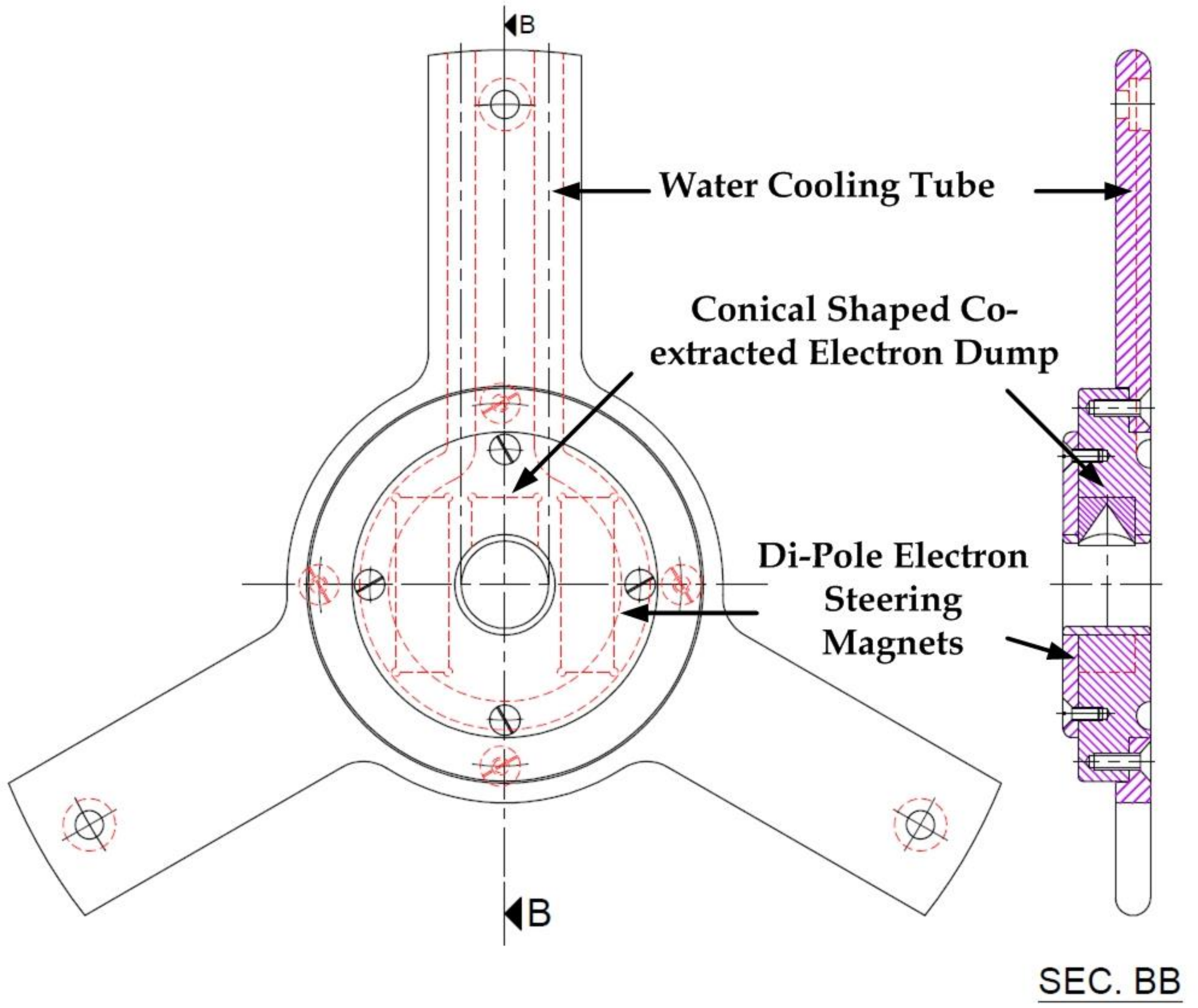
Cooling Arrangement for Main Plasma Chamber, Plasma Electrode, 2 MHz RF Antenna and Igniter



2D-CAD drawing of Hydrogen Plasma Generator

Extraction Electrode

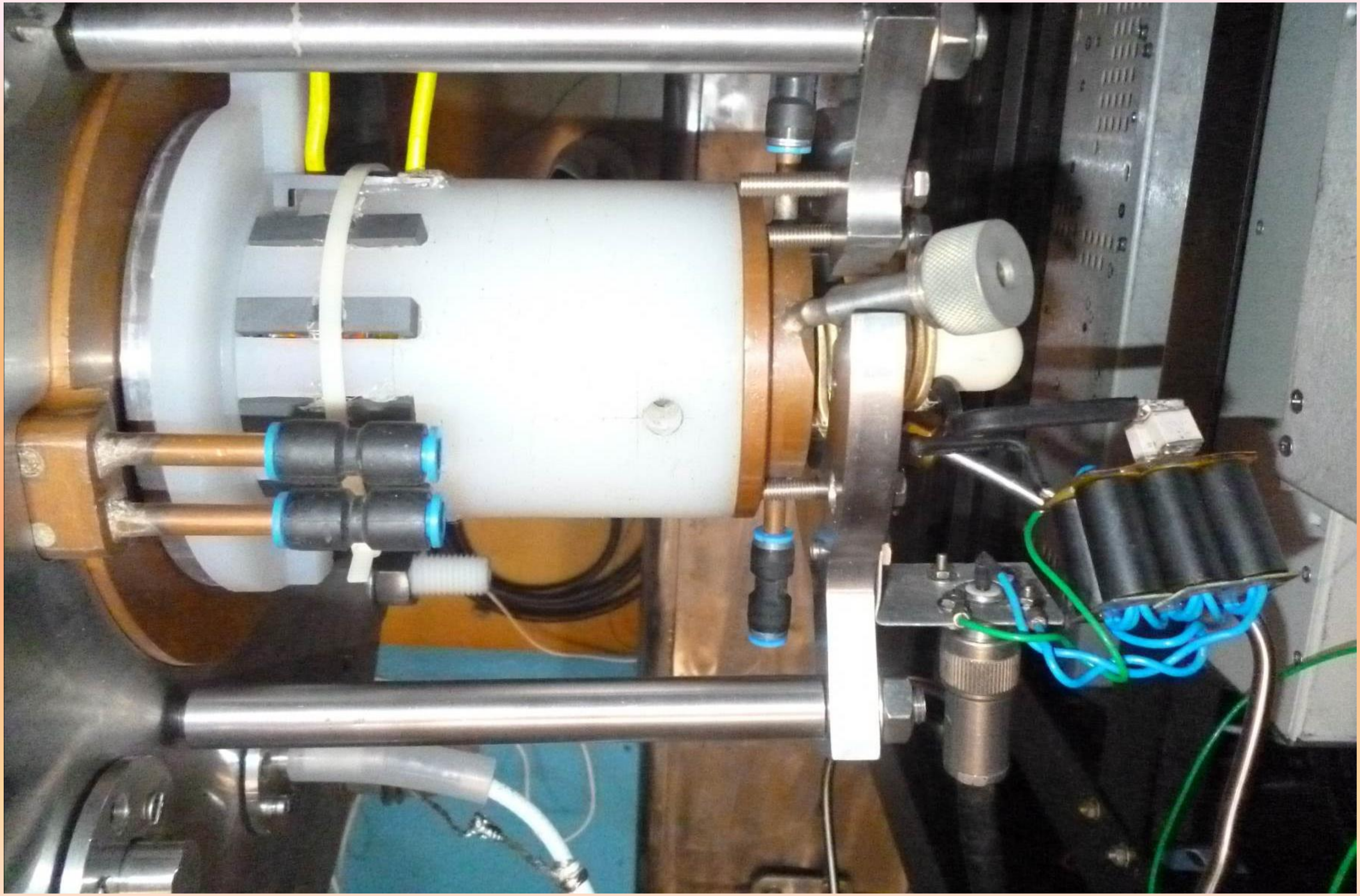
Extraction Electrode with Water Cooling Arrangement



2D-CAD drawing of Extraction Electrode

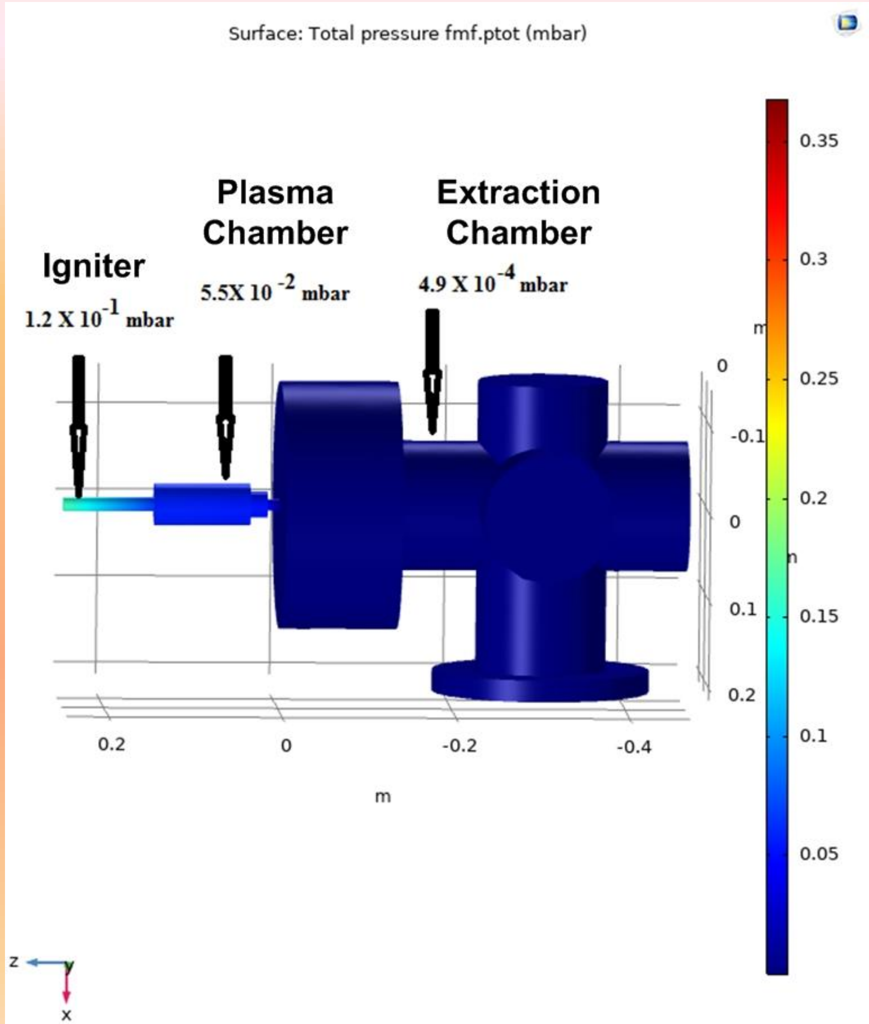
Assembled View of Main Plasma Chamber, Igniter and 2 MHz RF Antenna

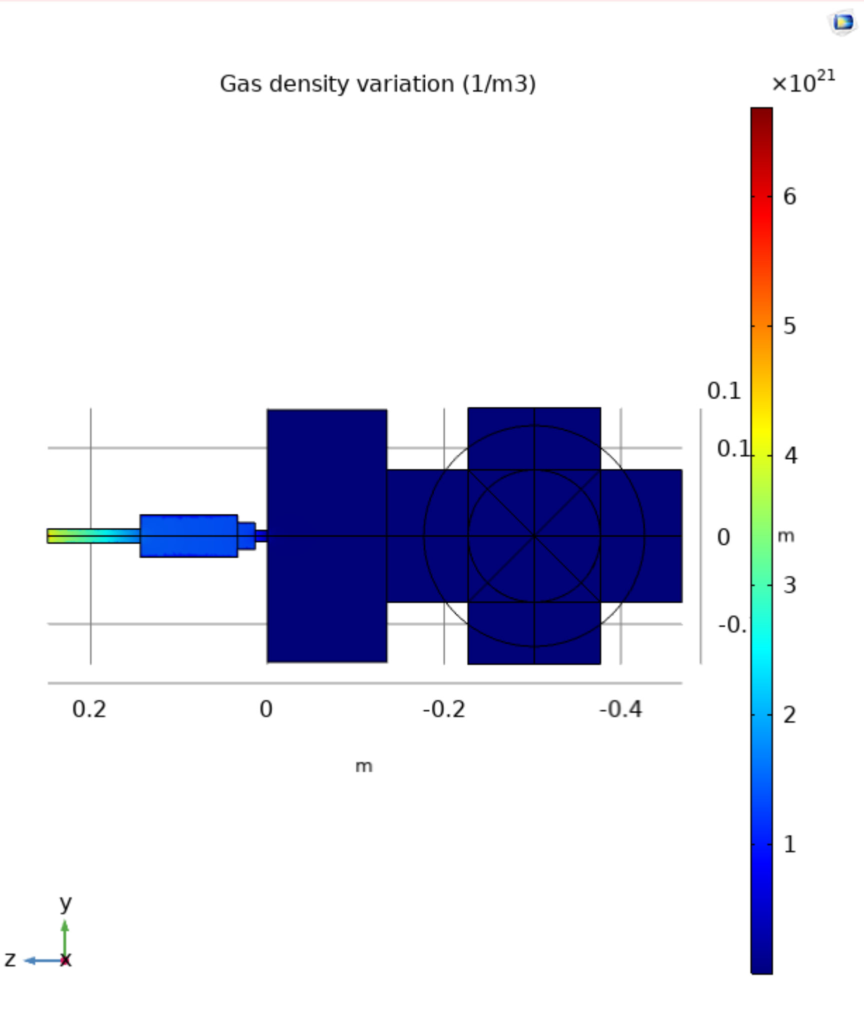
Main Plasma Chamber, Igniter and 2 MHz RF Antenna



Vacuum Simulation

Simulated Vacuum Levels in Various Parts of Ion Source

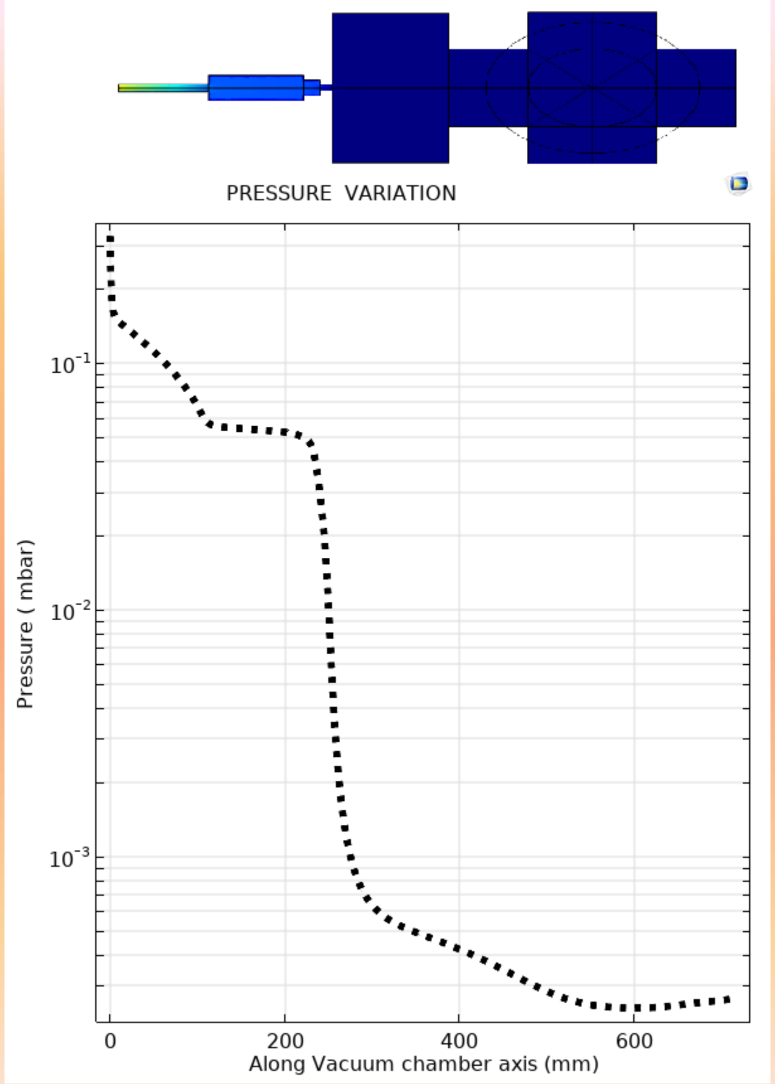


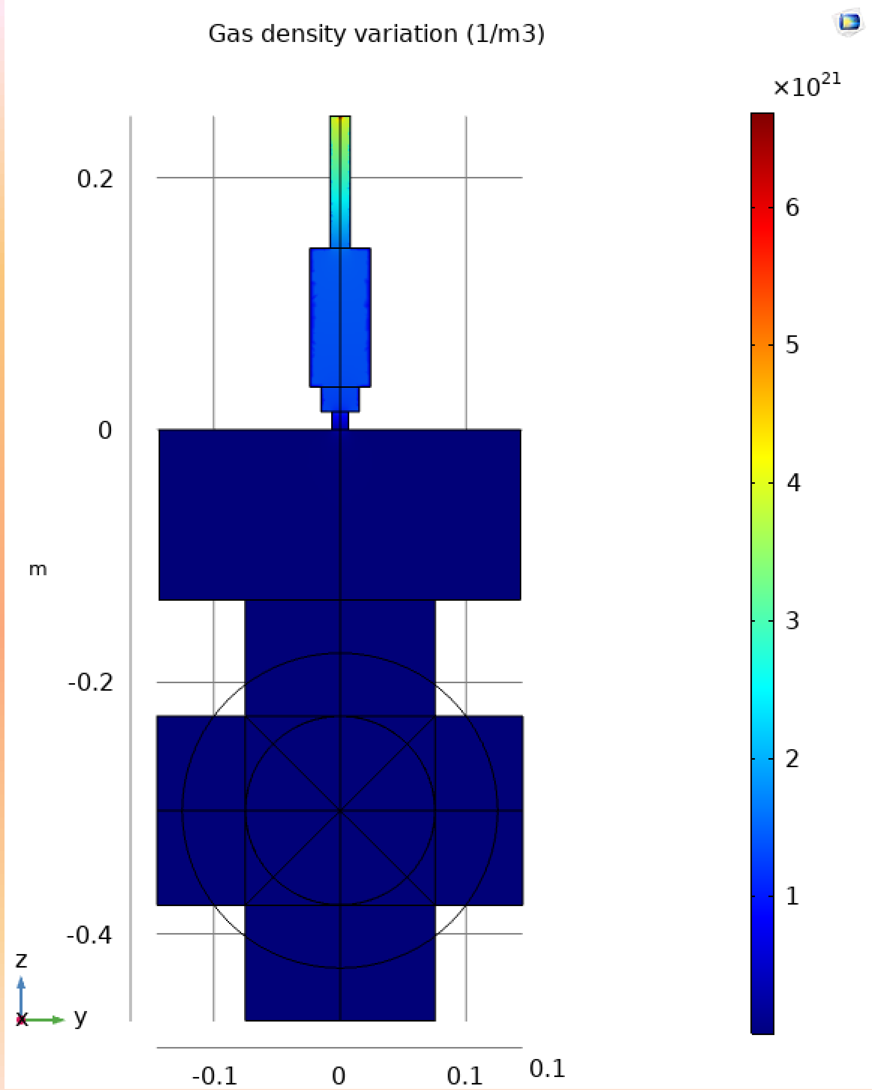


Hydrogen Flow Rate 35 SCCM, Igniter Aperture: Φ3 mm, Plasma Electrode Aperture: Φ6.5 mm, TMP 3 Nos. (2 X 500 LPS + 1700 LPS)

Vacuum Levels in Various Parts

Simulated Vacuum Levels in Various Parts of Ion Source

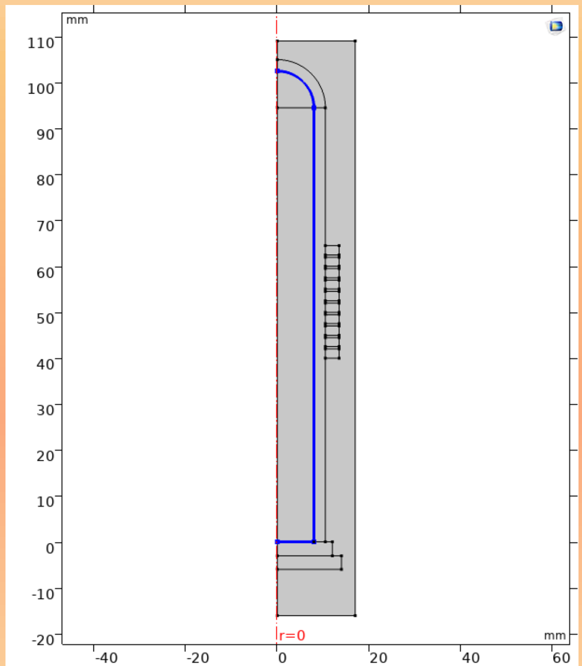




Thermal Simulation of Ignition System

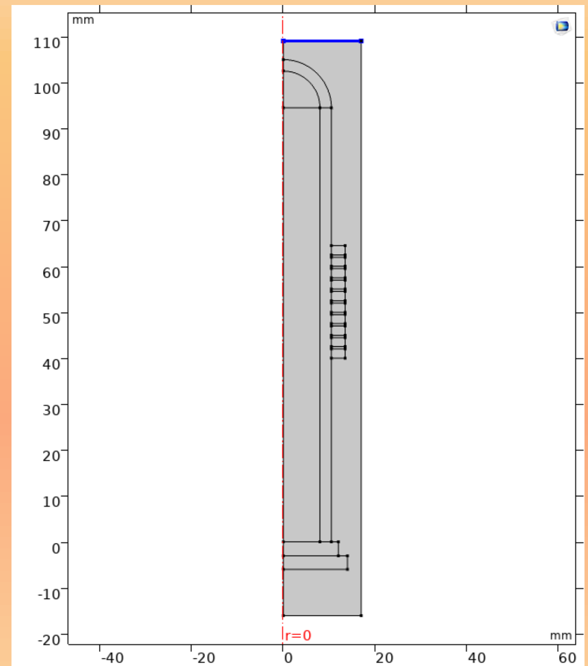
Thermal Simulation of Igniter

- The average power loss ~ 60 W
- The cooling air flow rate is 80 CFM at 298 K. 13.56 MHz external RF antenna wound tightly around the chamber (Chamber OD: 22 mm, ID: 16 mm)



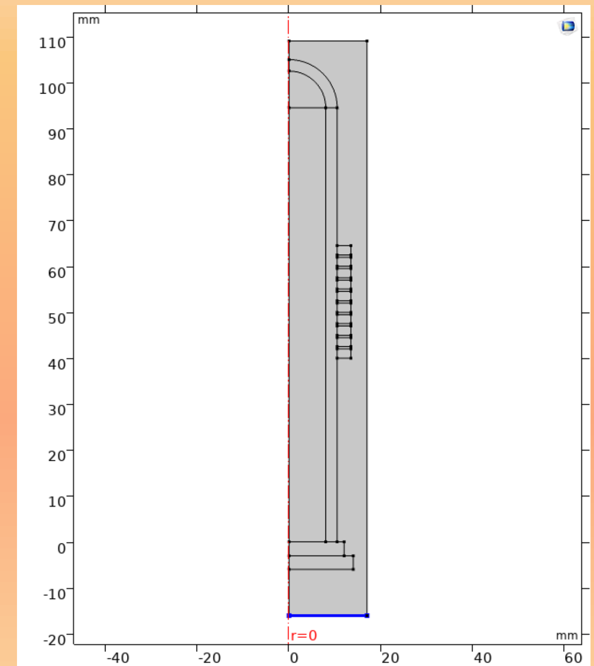
Heat Load on Igniter Chamber

(Total 60 W)



Air Flow Inlet

(80 CFM)

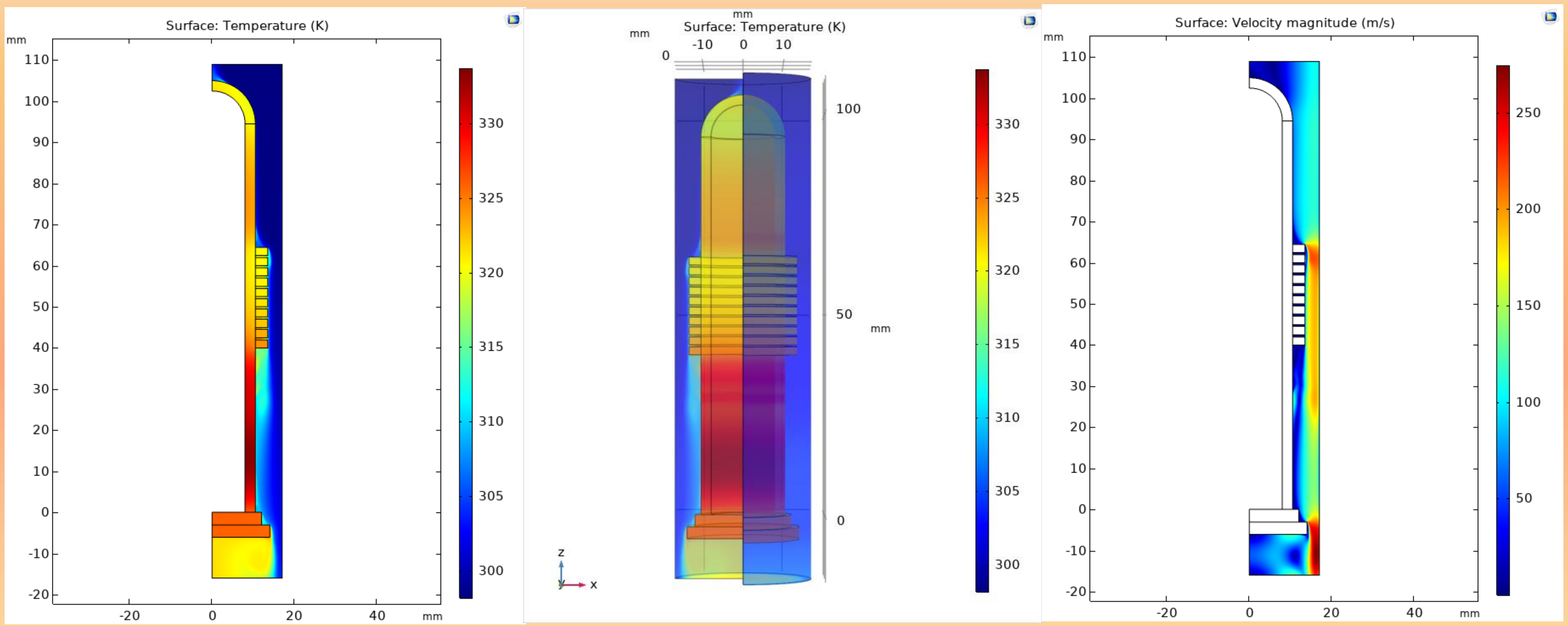


Air Flow Outlet

Temperature Rise in Ignition System

Thermal Simulation of Igniter

- The maximum temp. rise up to 334 K.
- The maximum temp. is in between 13.56 MHz RF antenna and open end of igniter tube.



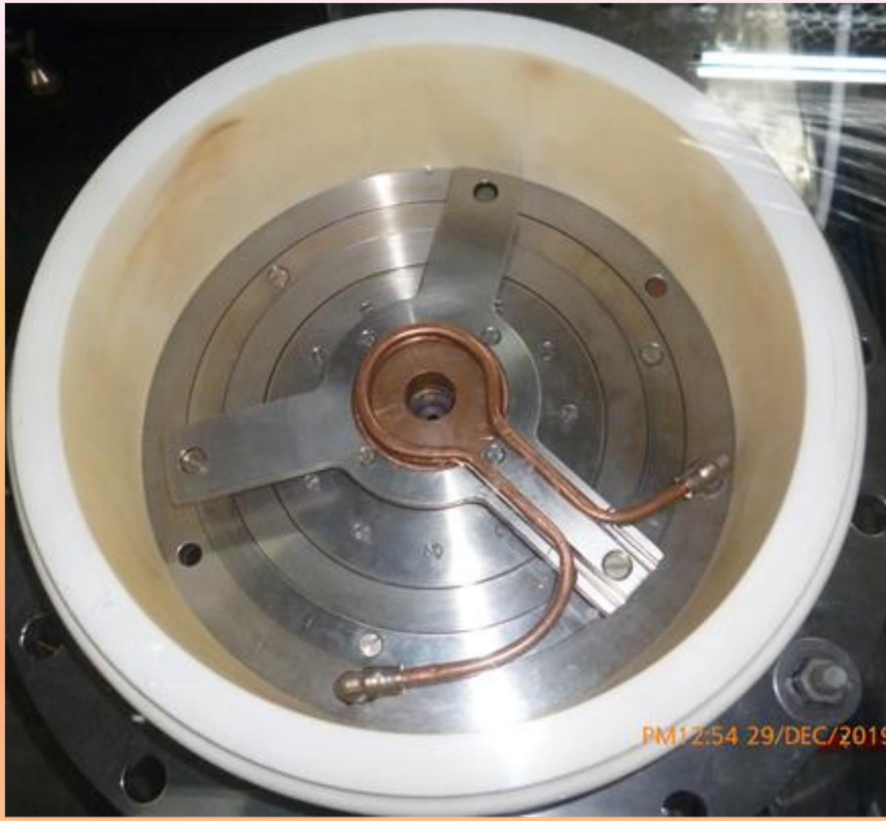
2D Temp. Distribution

3D Temp. Distribution

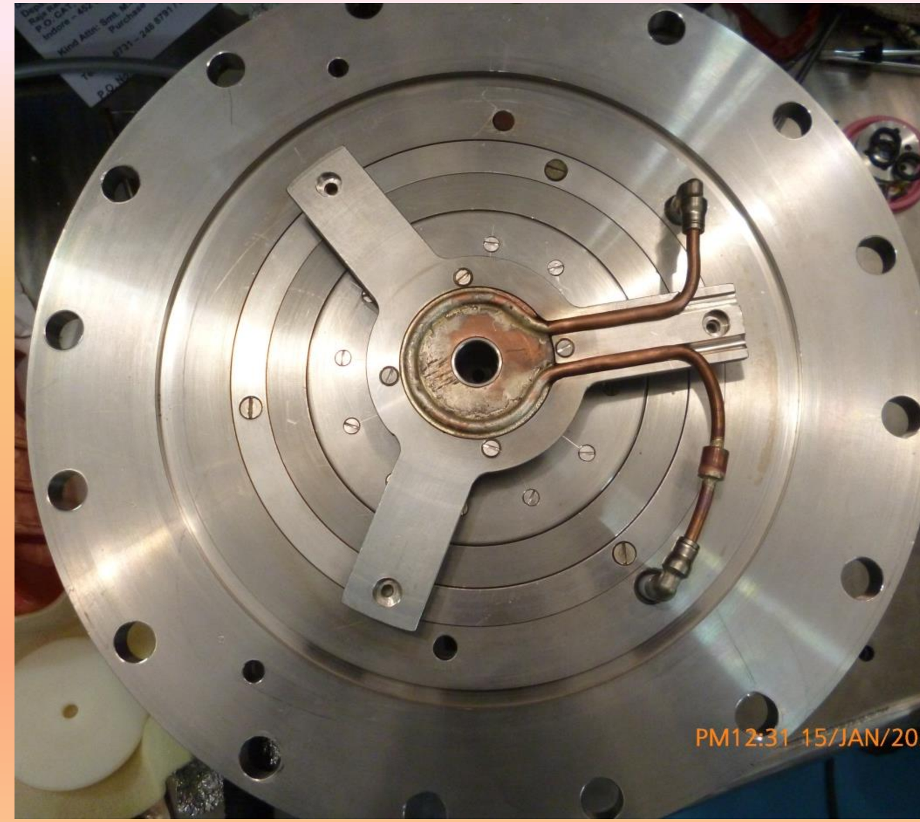
Air velocity 2D Distribution

Extraction Electrode with Water Cooling Arrangement

Extraction Electrode with Water Cooling Arrangement



Before Brazing

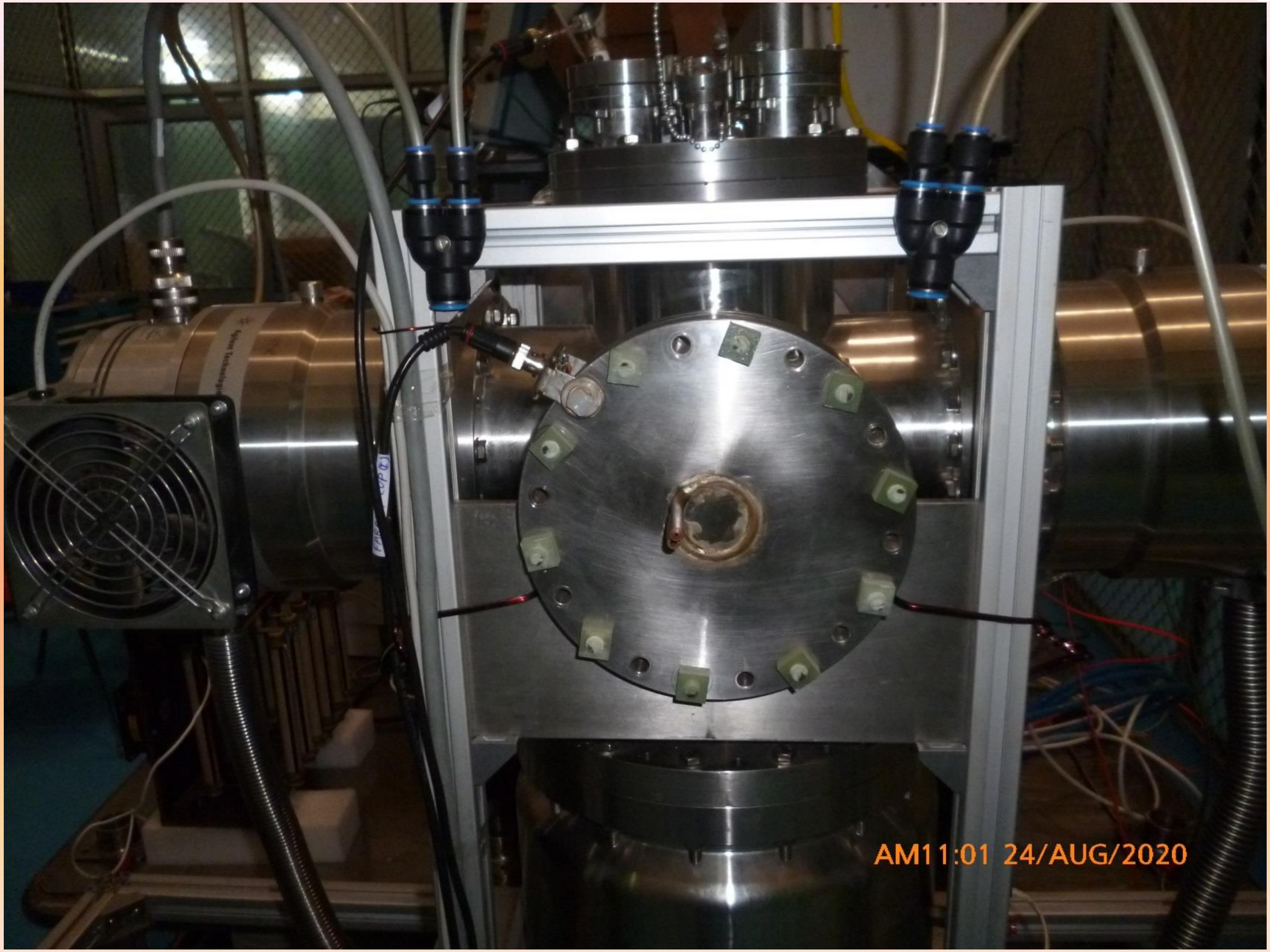


After Brazing

Extraction electrode was tested in open atmosphere with water cooling (LCW) arrangement at +15 kV DC.

Water Cooling Arrangement for Faraday Cup

Water Cooling Arrangement for Faraday Cup



Water Cooling Arrangement for 2 MHz RF Antenna, Plasma Chamber & Plasma Electrode

Water Cooling Arrangement for 2 MHz RF Antenna, Plasma Chamber & Plasma Electrode

Water Cooling Arrangement for Extraction Electrode

Water Cooling Arrangement for Extraction Electrode

Forced Air for Cooling Extraction Electrode and Plasma Electrode Biasing Network for HV Power Supply

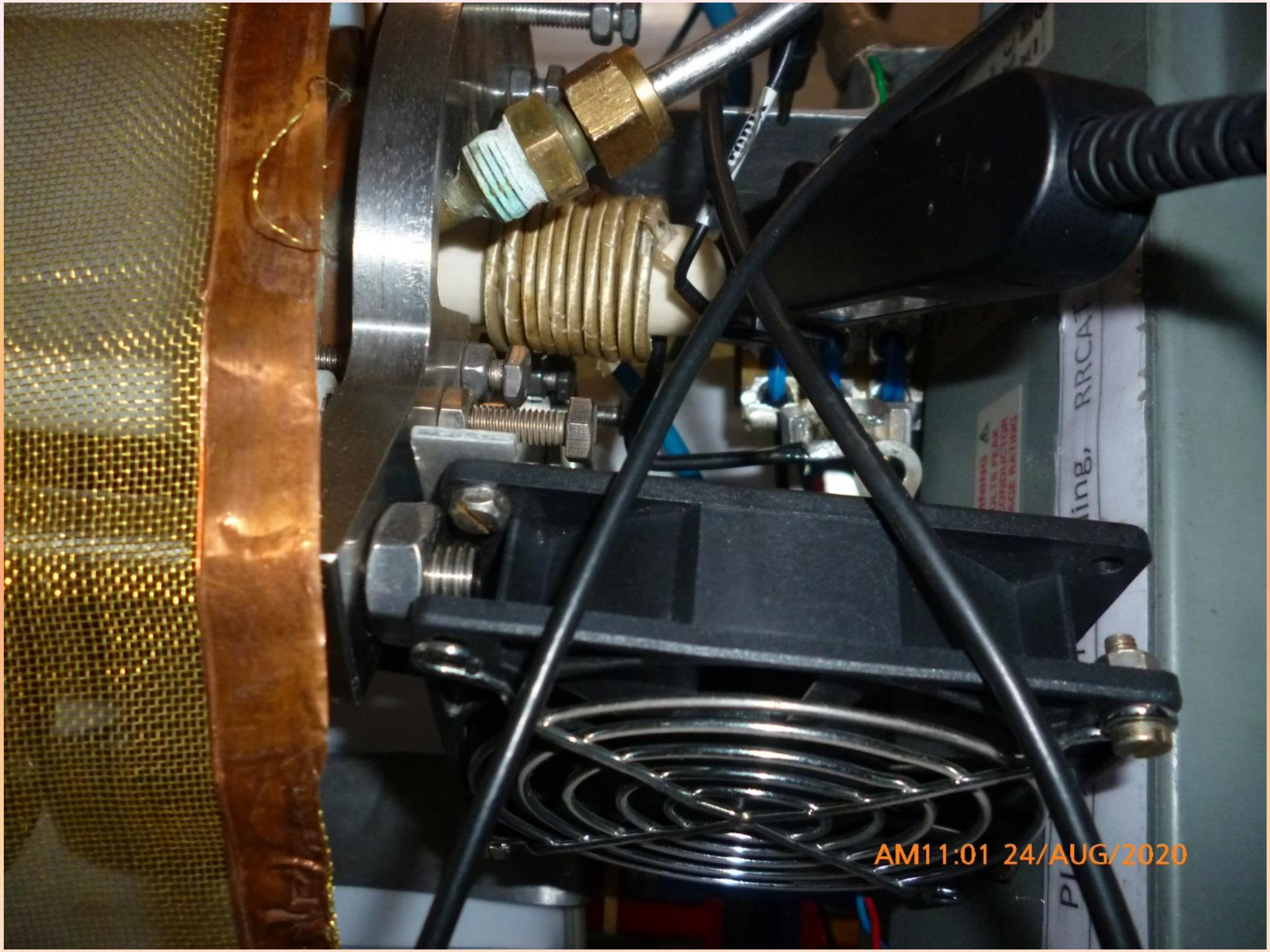
Forced Air Cooling Arrangement Provided for Extraction Electrode Biasing and Plasma Electrode Biasing Network for HV Power Supply

Extraction Electrode Biasing Network

Plasma Electrode (Acceleration) Biasing Network

Forced Air Cooling for Igniter and 13.56 MHz Antenna

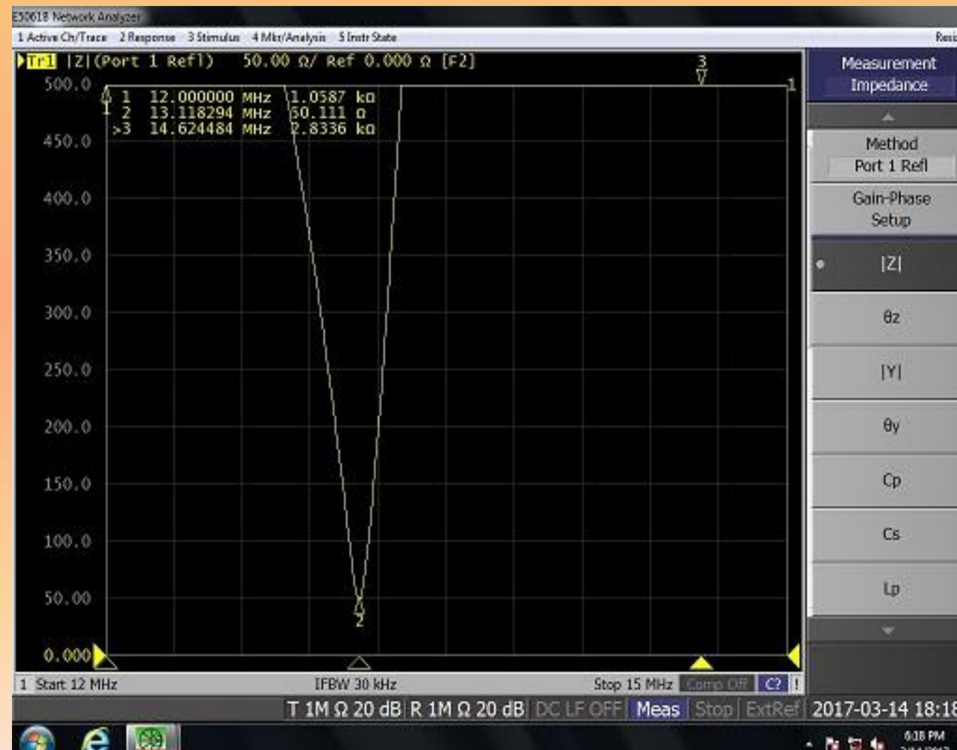
Forced Air Cooling Arrangement Provided for Igniter and 13.56 MHz Antenna



Pulsed Mode RF Ignition System

Ignition RF Matching Network

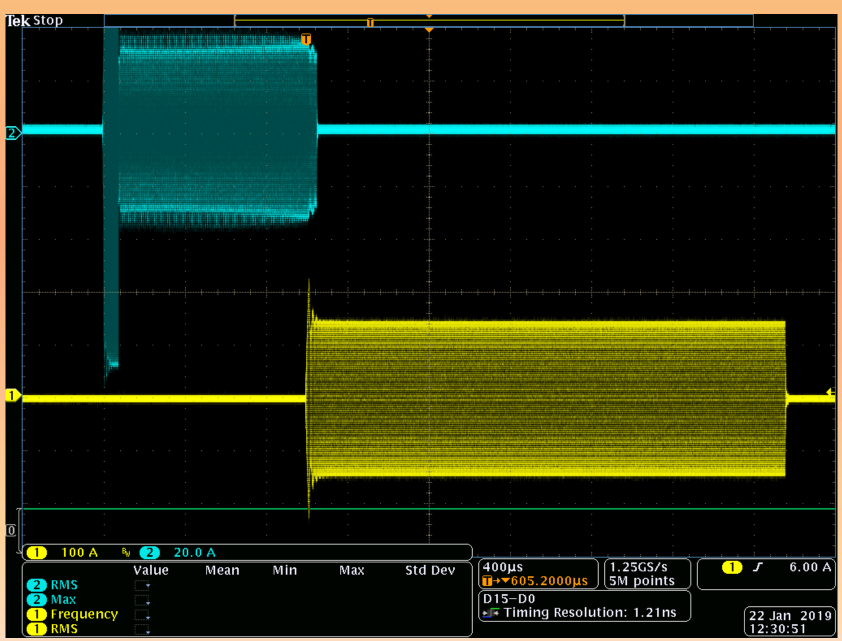
- A step-down RF transformer (turns ratio 9:1) and series resonance capacitor based matching network was developed to operate igniter reliably in pulse mode.
- It maximise the RF power coupling to plasma and generates maximum magnetic motive force (MMF in this case ~ 800 Amp-turns).
- The impedance of matching network measured with vector network analyser (VNA) is ~50 Ω.

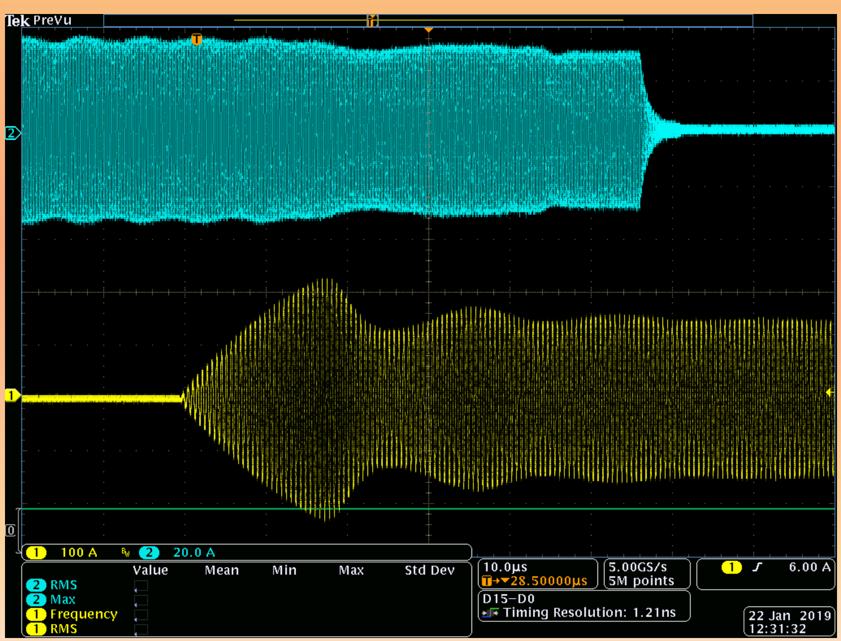


Pulsed Mode RF Ignition System Timings

Ignition and Main Plasma RF Antenna Current Waveforms

- To operate the ignition system reliably in pulsed mode following techniques are incorporated.
- The pulse width of 13.56 MHz RF power is kept 2 ms (minimum).
- Overlapping of 13.56 MHz and 2 MHz RF pulses for minimum 60 μs time duration.

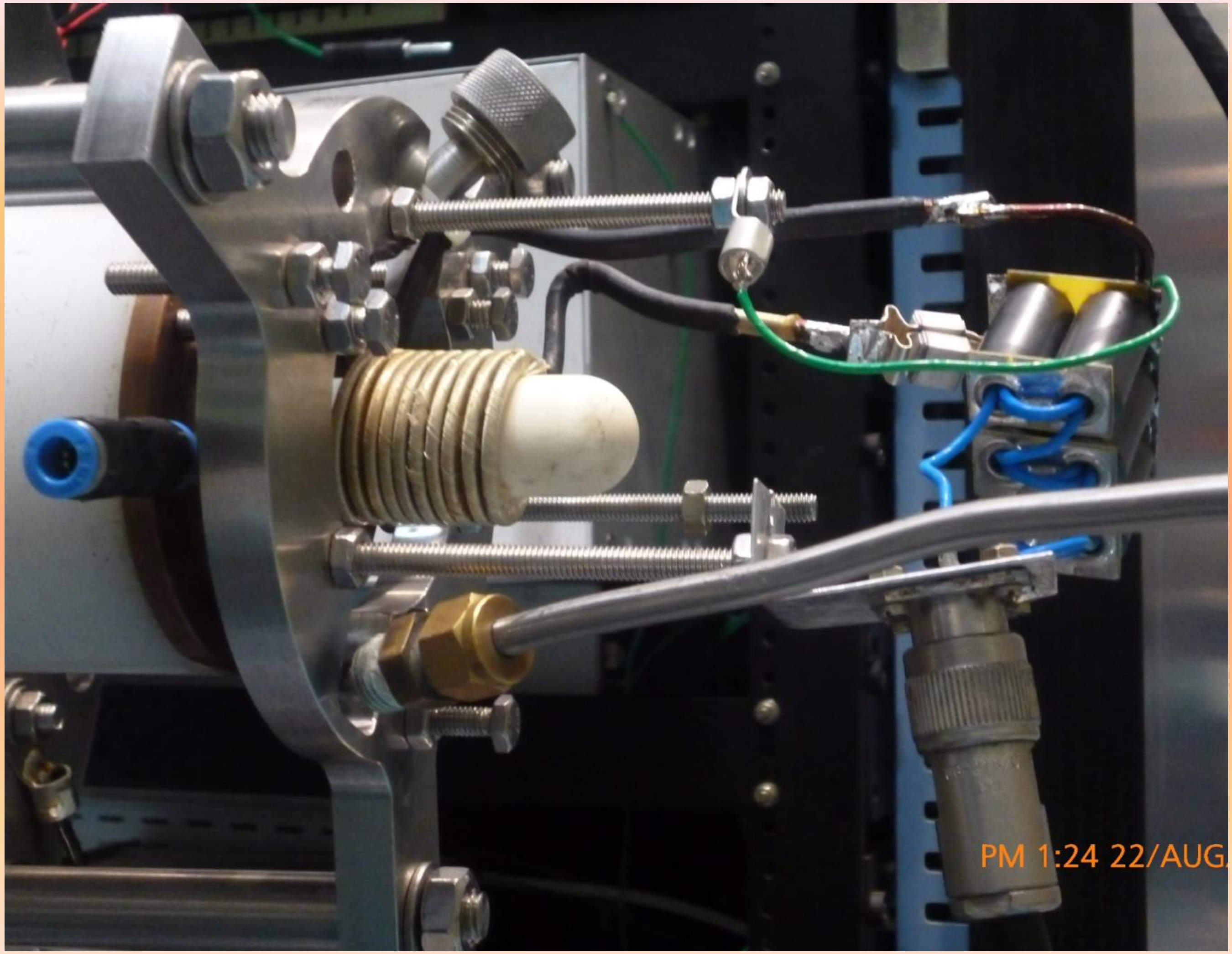




2 MHz and 13.56 MHz RF Antenna

Continue

The ignition antenna of 13.56 MHz and main plasma antenna of 2 MHz are physically separated.



2 MHz Pulsed RF Source Circuit

2 MHz pulsed RF Source Circuit Diagram

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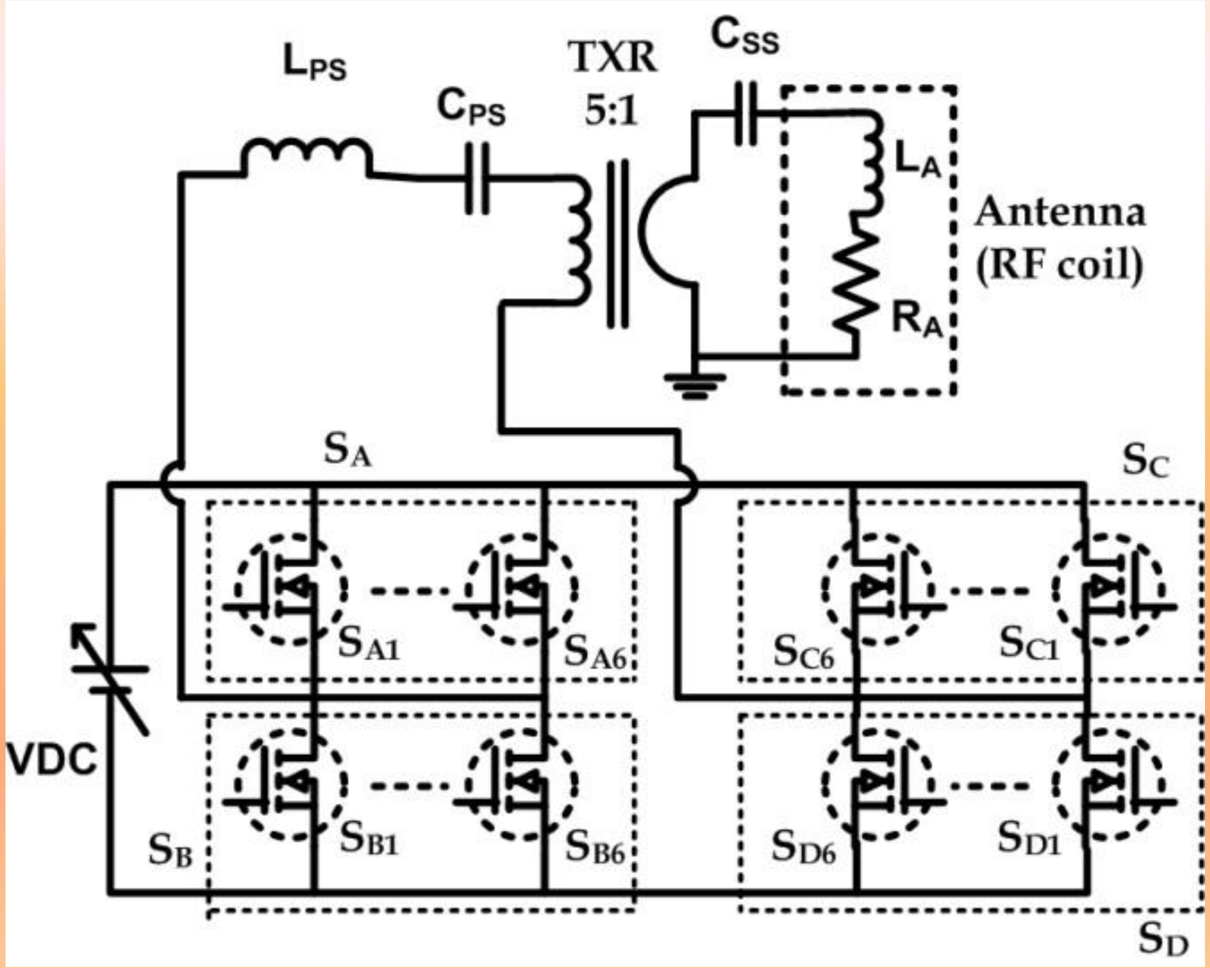
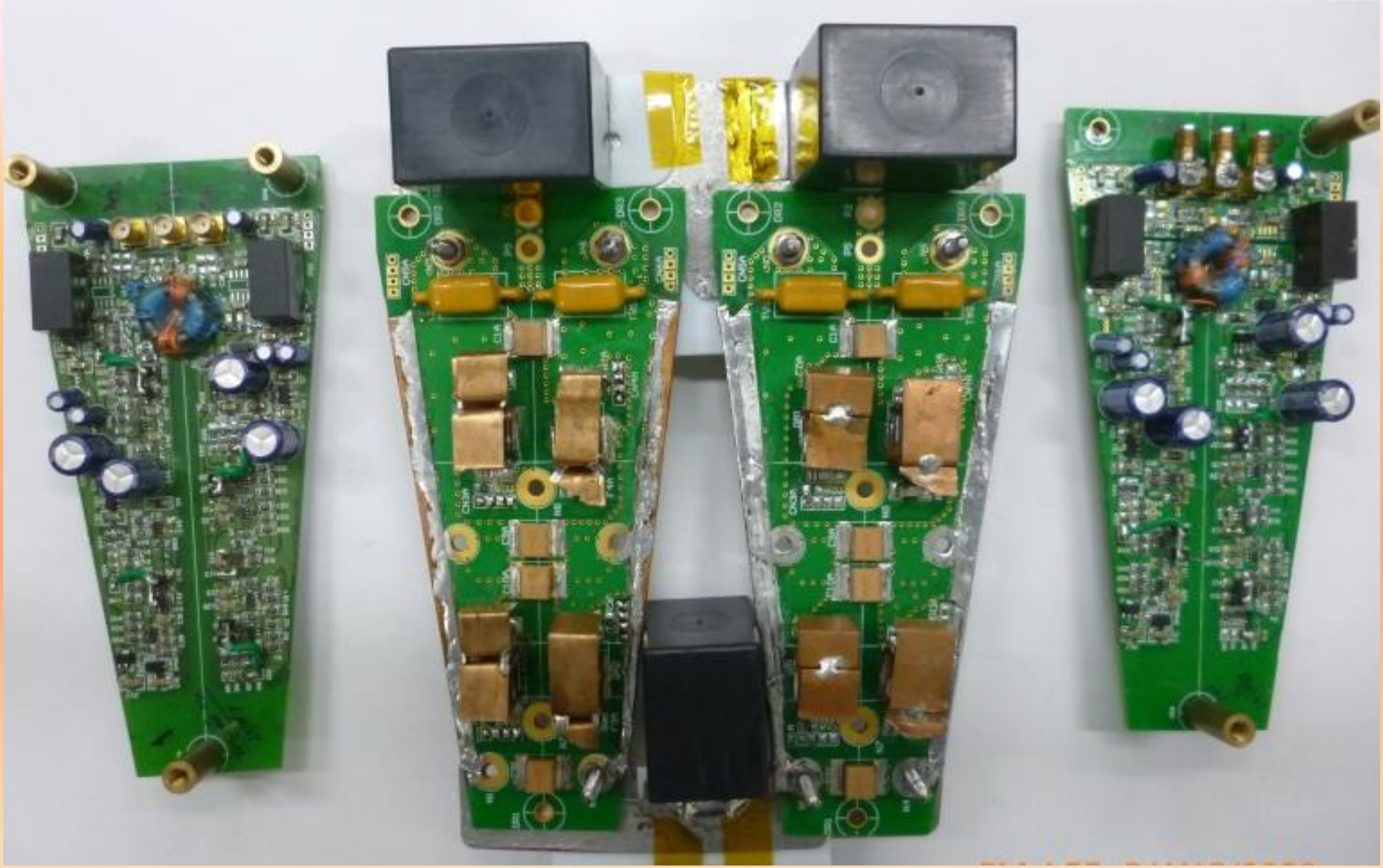


24 Nos. of SiCMOSFETs in Full-Bridge configuration, generates 2 MHz rectangular variable amplitude voltage pulses, two series resonant components converts this pulses to sine wave current in RF antenna. A step down Isolation Transformer (5:1 turns ratio) is used for current amplification.

2 MHz Inverter and Gate Driver Board

SiCMOSFETs Full-Bridge and isolated gate driver circuit boards



SiC MOSFET with copper heat sink for forced air cooling arrangement.
Transformer based isolated half-bridge gate driver circuit for SiC MOSFET

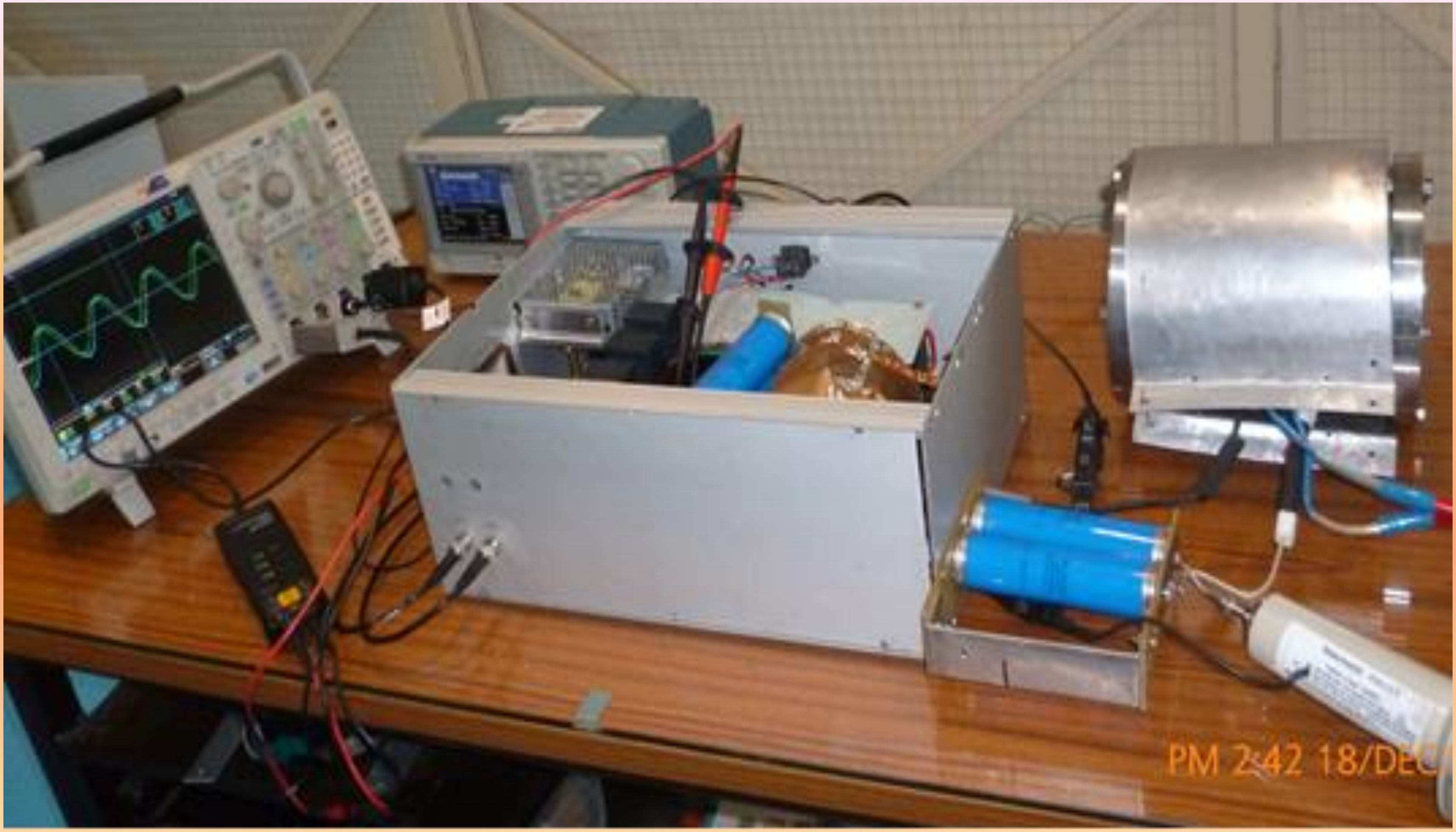
2 MHz Pulsed Source Assembly

2 MHz Pulsed RF Source with Inverter, Series Resonant Components and Step-down Isolation Transformer

2 MHz Pulsed RF source assembled in 4 U, 19 INCH electronics casing, consisting of DC capacitor bank, SiCMOSFET full-bridge inverter, primary series resonant component and step-down isolation RF transformer.

2 MHz Pulsed Source Testing Setup with Dummy Load

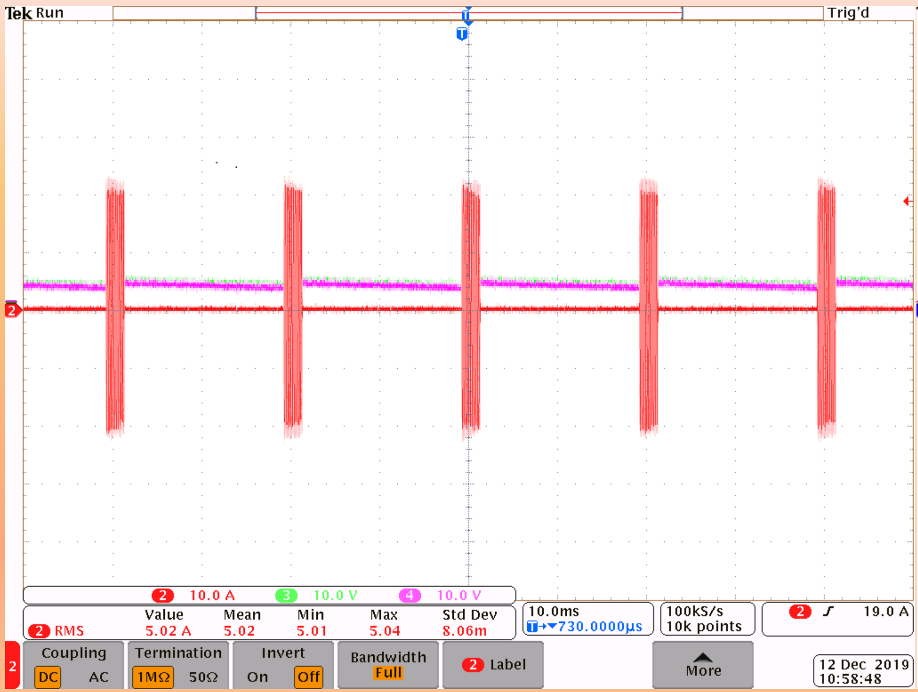
2 MHz Pulsed RF Source Testing Setup with Dummy Load

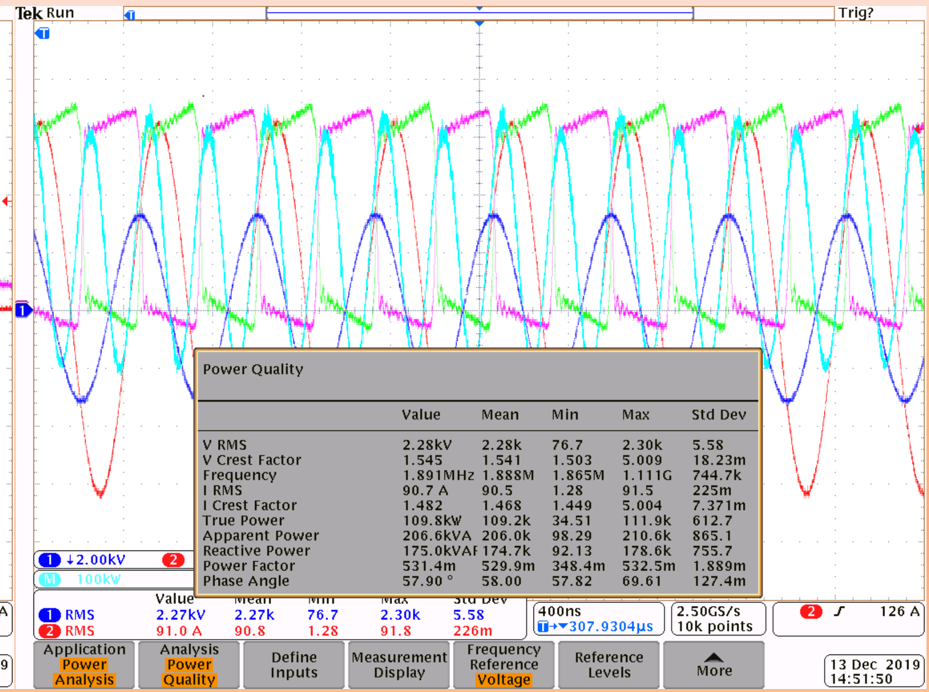


2 MHz pulsed RF source and external 6 turns water cooled RF antenna tested for supplying 90 A RMS antenna current with 2 ms pulse width at 50 Hz repetition rate, peak RF power delivered ~ 100 kW.

2 MHz Pulsed Source Test Results with Dummy Load

2 MHz Pulsed RF Source Test Results

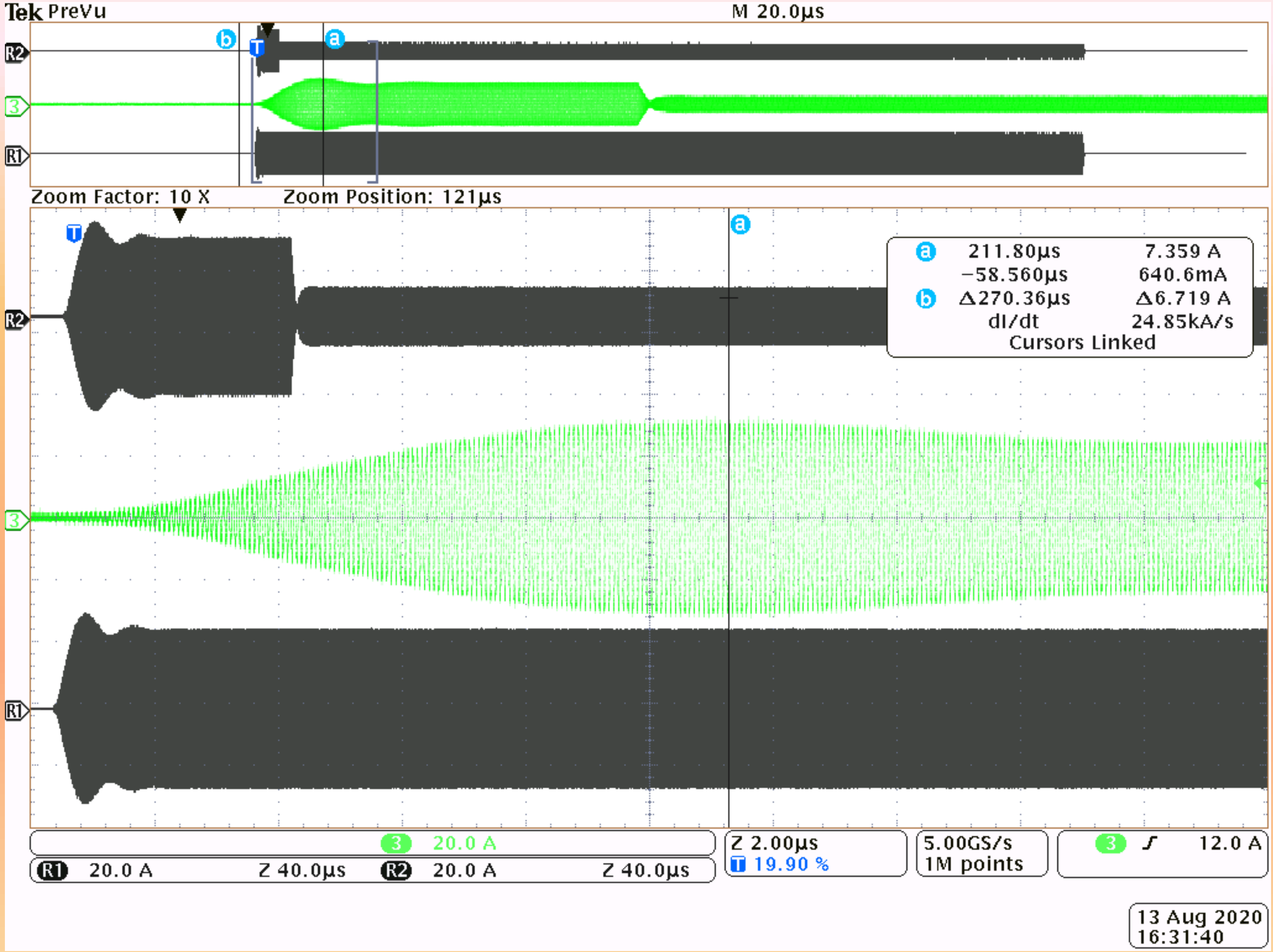




2 MHz pulsed RF source and external 6 turns water cooled RF antenna tested for supplying 90 A RMS antenna current, 2 ms pulse width at 50 Hz repetition rate with peak RF power of 100 kW

Pulsed 13.56 MHz Igniter Test Results

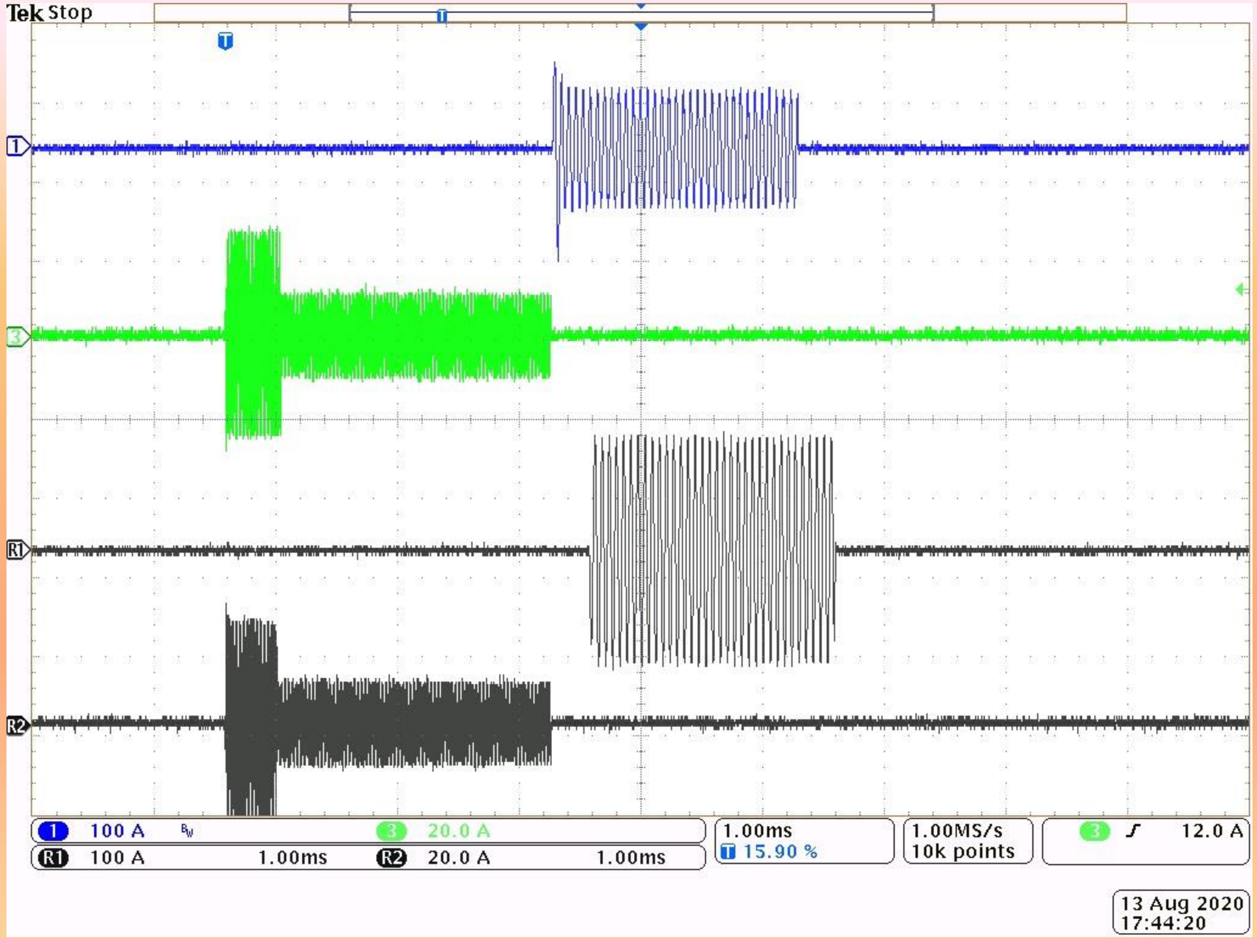
13.56 MHz Igniter Antenna Starting Current Transition Details With and Without Plasma



ChR2: 13.56 MHz igniter antenna current with plasma, **ChR1: 13.56 MHz igniter antenna current without plasma** Ch1: 13.56 MHz igniter antenna current at starting of pulse

Pulsed 13.56 MHz and 2 MHz Pulsed Timing Test Results

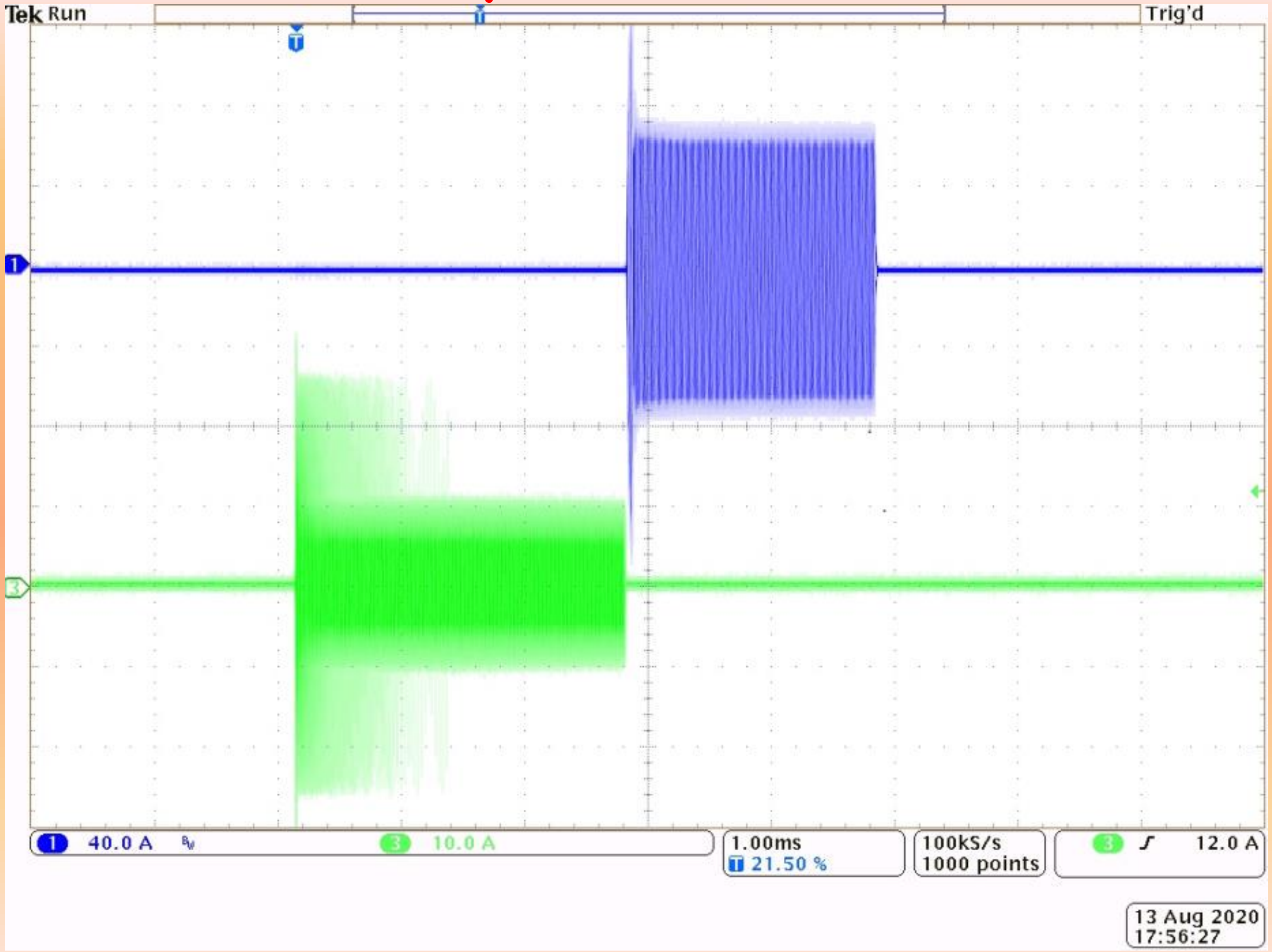
Sufficient over lapping of igniter 13.56 MHz and main plasma 2 MHz antenna current is required for reliable operation in pulsed mode



Ch1 : 2 MHz antenna current, Ch2 : 13.56 MHz antenna current,
Main Plasma starts reliably.
ChR1: 2 MHz antenna current, ChR2: 13.56 MHz antenna current,
Main Plasma failed to start.

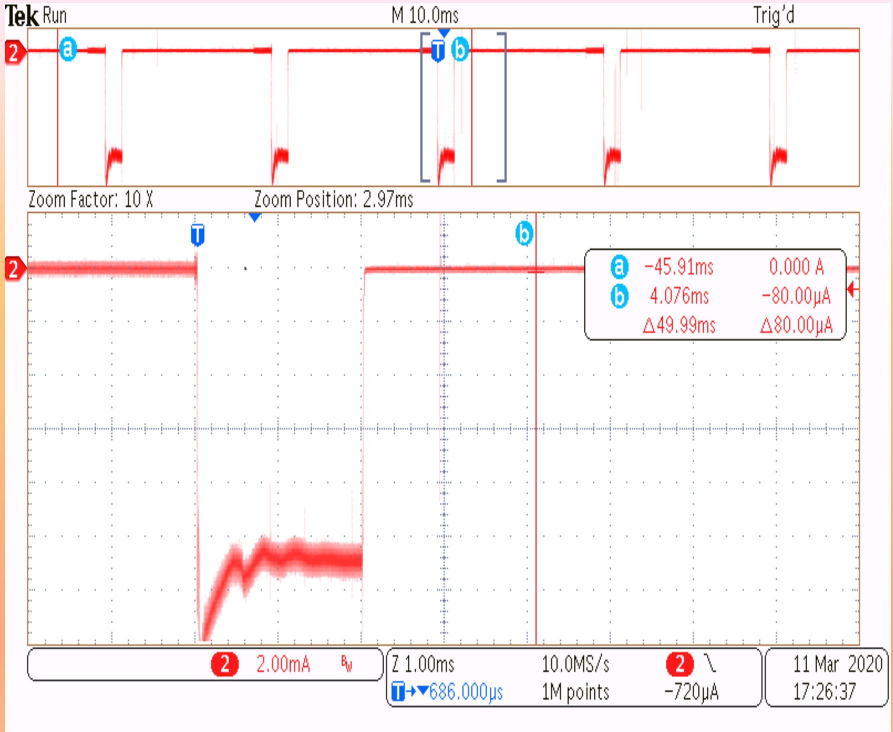
Recorded Persistence of View for 13.56 MHz and 2 MHz Antenna Current

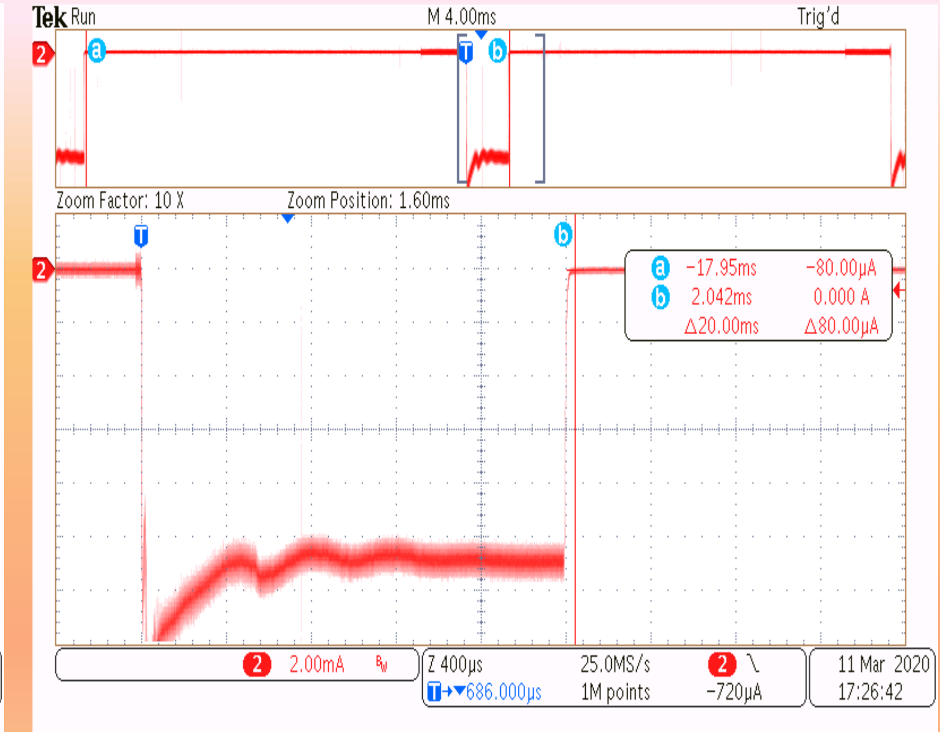
Recorded persistence mode view for 2 MHz antenna current and 13.56 MHz antenna current, this waveform confirms igniter starts reliably within 1.2 ms.



Recorded Beam Current Waveform

Recorded Beam Current Waveform

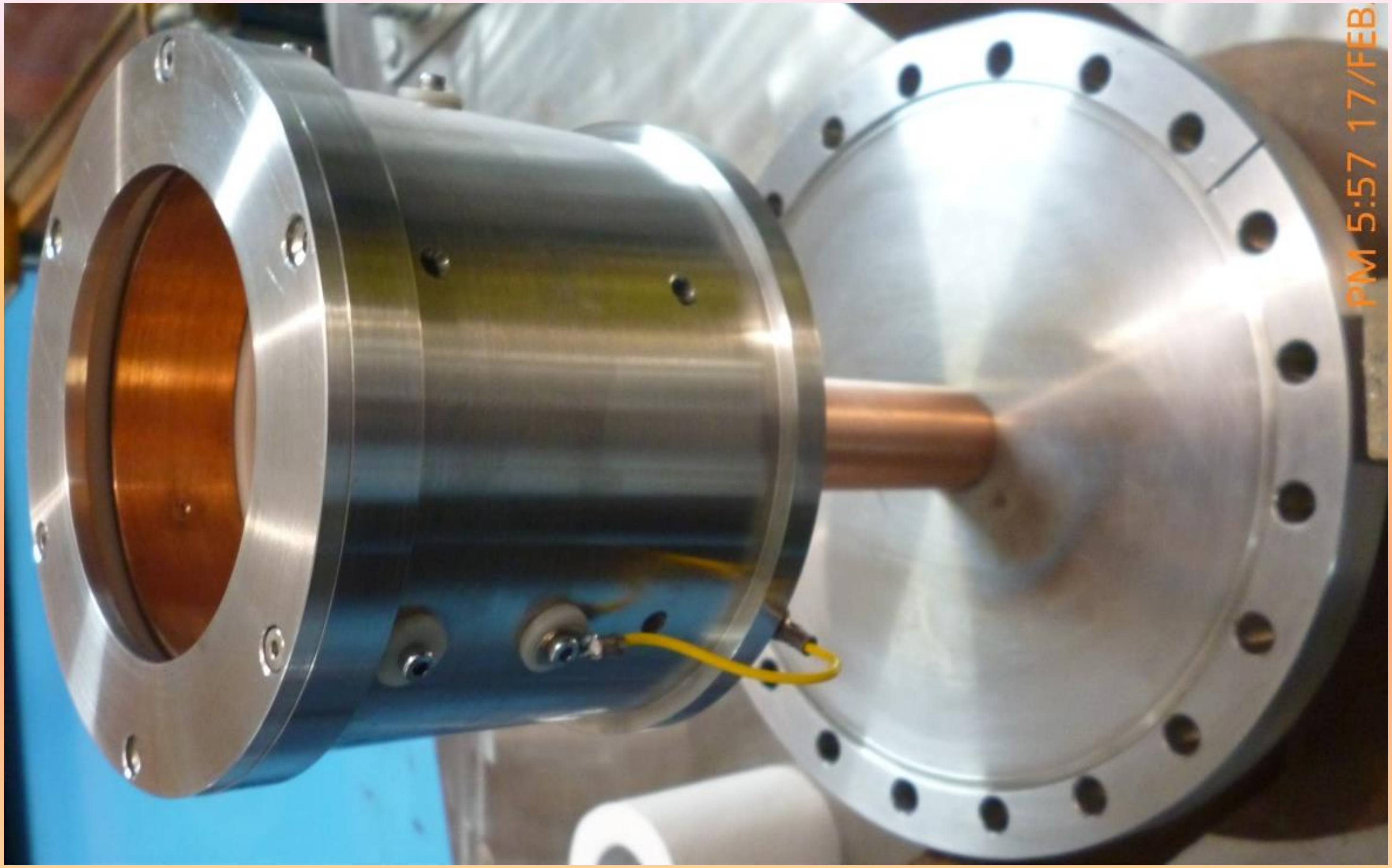




11 mA beam current pulsed at 2 ms pulse width, 50 Hz repetition rate (10% duty factor) recorded up to 50 keV beam energy. The beam current was dumped in a water cooled Faraday cup.

Biased Faraday Cup for Ion Beam Current Measurement

Biased Faraday Cup for Ion Beam Current Measurement



- ✓ The extracted H- ion beam current measured using biased Faraday cup.
- ✓ The cone shaped collector and biasing ring are fabricated in OFC copper.

Conclusions

Conclusions

- The pulsed RF source at 2 MHz, 100 kW was successfully demonstrated at 2 ms pulse width, 50 Hz repetition rate (10% duty factor).
- The RF source major components like RF antenna and matching network were designed and developed successfully.
- The measured negative hydrogen current up to 50 keV beam energy is 11 mA (pulsed 2 ms and 50 Hz, 10% duty factor).
- The beam current was dumped in a water cooled Faraday cup.
- The major components were water cooled like main plasma chamber, 2 MHz RF antenna, plasma electrode, extraction electrode etc.
- The ion source components were provided forced air cooling like igniter chamber, igniter RF antenna and matching network, 2 MHz RF source and its matching network, current stabilizing network of HVPS.

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Shri Om Prakash,

and Shri S. K. Sonawane

during various stages of development of the RF based negative hydrogen ion source.

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Thanks

Q & A

For any question

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