doubleMOT USER MANUAL

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Table of Contents

1. General Information

1.1 User Facilities Requirements

Ensure your lab or experimental setup has ample room to work around the doubleMOT for installation and laser safety. Always follow your institutional guidelines concerning a safe work environment. Infleqtion recommends the following environmental conditions:

- Temperature: 10°C to 30°C
- Relative humidity: 0 to 95% (non-condensing)
- Input voltage: 100-240 V_{ac} (+/- 10%)
- Input frequency: 50/60 Hz
- Input power: 160 VA

1.2 Package Contents

Upon receiving the doubleMOT, inspect the packaging for damage. If the packaging shows signs of damage, excessive shock or if the shock watch is red, notify the shipping company and then contact Infleqtion.

When unpacking the doubleMOT, be particularly careful to avoid dropping it or knocking it against anything. Carefully remove the doubleMOT and all the accessories and inspect for any damage. Please contact Infleqtion if there are signs of damage to the product. **Keep all original packing materials.**

The shipment should contain the following items:

- doubleMOT cold atom assembly
- Power cord
- Agilent IPC Mini ion pump controller
- Ion pump magnet assembly
- High voltage cable
- 2D MOT magnet assembly (if ordered)
- TriCoil assembly (if ordered)
- Coil assembly cable (if TriCoil assembly is ordered)
- Picas (if ordered)
- User Manual (sent digitally)

If any of these items are missing, please contact Infleqtion to obtain replacements.

Upon receipt of your doubleMOT product we advise that the package is opened, and the unit is powered ON.

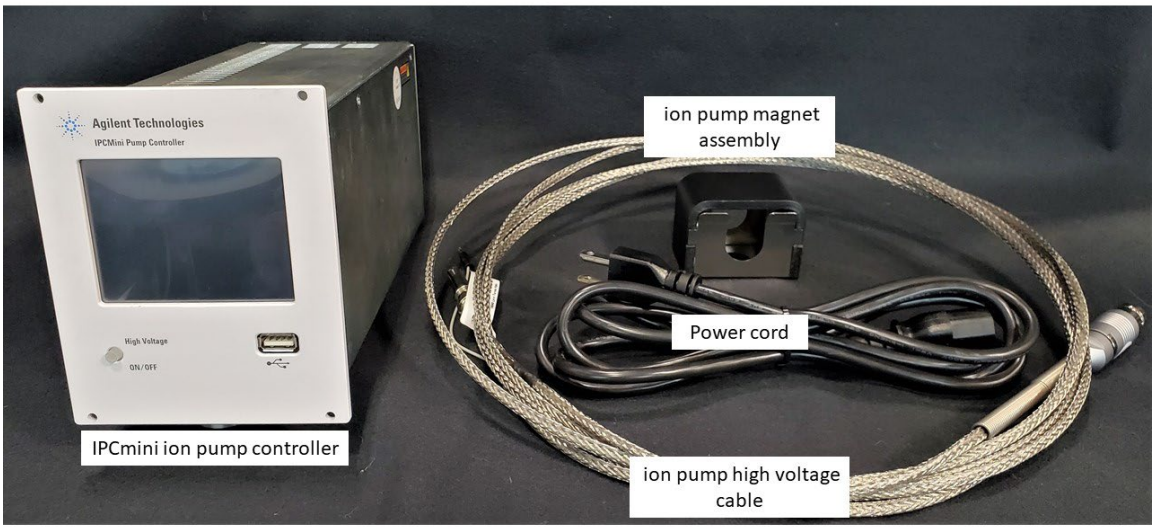


Figure 1: Accessories shipped with the doubleMOT.

2. Safety

2.1 Definitions, Labels and Symbols

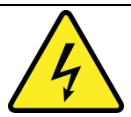
The following safety terms are used in this manual:

The **DANGER!** heading explains danger that could result in personal injury or death.

The **CAUTION!** heading explains the hazards that could damage the instrument.

The **NOTE!** heading provides information to the user that may be beneficial in the use of the instrument.

NOTE Before operating the doubleMOT please read this manual carefully to prevent personal injury and damage to the device. The following safety instructions must be always adhered to. The following symbols are used in this manual:

Symbol	Description
	Caution! – Risk of electric shock
	Caution! – Risk of damage to equipment

2.2 Warnings

	**Before using the doubleMOT for the first time, follow the instructions in the Unpacking Guide to ensure that the vacuum was not compromised during shipping.** If the doubleMOT is not working properly upon arrival, please contact Infleqtion within 5 business days using sales@Infleqtion.com.
	**Never tighten or loosen any of the vacuum bolts on this product.** These bolts form ultra-high vacuum (UHV) seals. They are tightened to a torque level that ensures these seals remain UHV-compatible over the life of the product, which can be 5 years under normal operating conditions. Tampering with these bolts may irreversibly compromise the vacuum and **void the warranty**. Please review Infleqtion's terms of sale, which can be found in Section 8.
	**There are no serviceable parts inside this product.** Work performed by persons not authorized by Infleqtion **will void the warranty**.
	**Do NOT apply more than 4.5 A of current to the dispenser.** Applying more than 4.5 A, even for just a few seconds, will release a significant quantity of alkali atoms from the dispenser, enough to completely coat the walls of the glass chamber. This not only depletes the available alkali atoms in the dispenser, but it also leaves the MOT chamber opaque to laser beams. The ion pump will saturate, if not fail altogether, under the high alkali atom load. **We strongly recommend using a fuse or circuit breaker to protect the alkali atom dispenser from receiving too much current.**

2.3 Physical Safety

The system is composed of two glass cells held under vacuum. Take caution while working with your hands or tools to avoid contact with the glass cells.

DANGER! **CAUTION!**	Care should be taken to avoid contact with the glass cells with either hands or tools. Broken glass components can create a sharps hazard to the end user and cause detrimental damage to the unit.

The ion pump magnet, 2D MOT permanent magnets, and TriCoil all produce magnetic fields. Take caution if necessary.

DANGER!	If you are wearing magnetic implants, take care to keep away from the magnets. Always warn anyone wearing such implants of the presence of the magnetic field. Anyone with any magnetically sensitive implants should consult their medical doctor regarding any potential applications.
DANGER! **CAUTION!**	The magnetic fields that extend beyond the protective housings of the device(s) can attract other magnetic materials. Keep small ferromagnetic objects like tools, razor blades, or screws away from the devices.

2.4 Electrical Safety

DANGER! **CAUTION!**	Care should be taken while handling the ion pump and corresponding cable. The ion pump controller can output a DC voltage of up to 7000 V. Take all necessary safety precautions during use. Refer to the ion pump product manual for detailed user instructions. www.agilent.com/cs/library/usermanuals/public/IPCMini.PDF

2.5 Laser Safety

Disclaimer	This is not a laser product. This is for reference only. Please refer to the manufacturer manual and safety information for each laser system that you will use with this product. Please follow your institutional guidelines concerning laser safety.
DANGER!	If the equipment is used in a manner not specified by the manufacturer, then the protection provided by the equipment may be impaired.

3. Specifications

Parameter		
External Dimensions	h × w × d h × w × d	4.9 x 4.9 x 9.5 in 12.5 x 12.5 x 24 cm
Weight	vacuum chamber only	2 lbs. 0.9 kg
Weight	With all mounting hardware	8.6 lbs. 3.9 kg.
Electrical	Current Voltage Frequency	300 mA 110 V 60 Hz
Science Cell Vacuum		< 0.8 nTorr
Residual Magnetic Field from Ion Pump	At cell center	< 0.5 G
Alkali Metal Source (for Dispensing Rates)	Natural Abundance	SAES
Ion Pump Speed		2 L/s
Alkali Source Resistance		<1 Ohm
Dispenser Operating Current		2.0 - 3.7 A
Typical Flux*		> 1 x 10^8 atoms/sec
Typical MOT Size*		> 5 x 10^8 atoms
Typical MOT Lifetime*		>40 1/e seconds

*These values are dependent on the exact experimental configuration and laser sources used

4. Regular Product Maintenance

4.1 Handling

The system requires no routine maintenance. Please keep the doubleMOT plugged into the ion pump with the ion pump on. If the system will not be in use for an extended period, keep the unit plugged into the ion pump, with the alkali dispenser set to “0” and **keep the ion pump on.**

4.2 Cleaning

Only use optics-grade solvents (methanol or iso-propanol alcohol), cleaning materials, and techniques to clean the glass surfaces of this product.

5. Installation

5.1 Mounting

Before any further installation, please ensure the doubleMOT is securely mounted to an optical table. Secure the feet using a standard 1” clamping fork.

The doubleMOT may be mounted horizontally. Please contact Infleqtion if your experimental setup requires this.

5.1.1 Ion Pump Set Up

1. *Attach the ion pump magnet assembly*

The ion pump magnet assembly consists of a magnet (black) and a fixing clip (silver). Following the orientation shown in Figure 2, place the magnet above the pump and the fixing clip below the pump. Push the two pieces together around the pump until the four metal tabs on the fixing clip snap into place. The magnet and fixing clip should fit snugly around the pump, as shown in Figure 2(b).

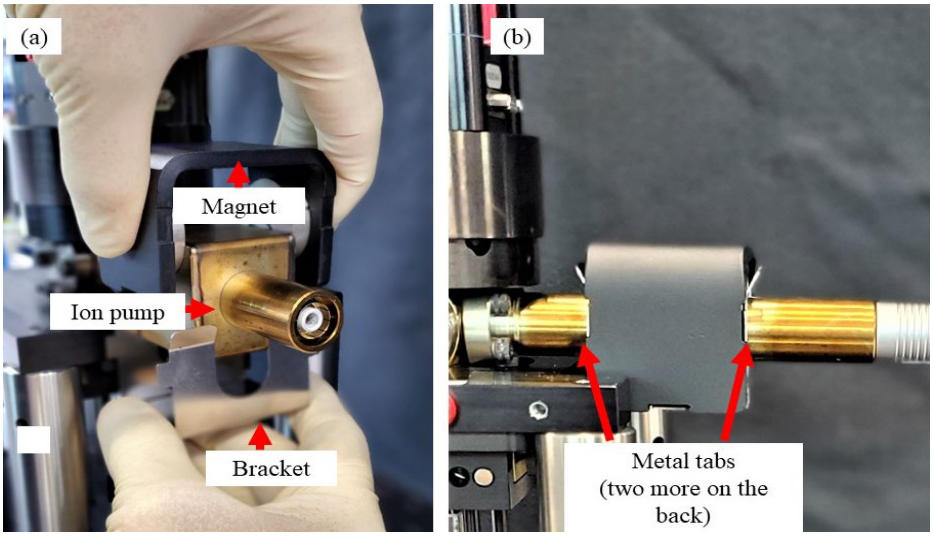


Figure 2. Attaching the magnet assembly to the ion pump.

WARNING!

ION PUMP PROTECTION – DO NOT turn on the ion pump controller until Step 4.

2. *Unpack the ion pump controller.*

The ion pump is controlled by an Agilent IPCMini ion pump controller. An AC power cord for powering this controller is included.

WARNING!

HIGH VOLTAGE – The ion pump controller can output a DC voltage of up to 7000 V. Take all necessary safety precautions during use.

3. *Connect the high-voltage (HV) cable.*

Connect the HV cable to the "HIGH VOLTAGE OUTPUT" jack on the rear face of the controller as shown in Figure 5(a). The ICPMini controller is equipped with a high voltage interlock. To override this interlock, insert the black banana plug that is attached to the HV cable as shown in Figure 3(a). Insert the other end of the HV cable into the ion pump as shown in Figure 3(b).

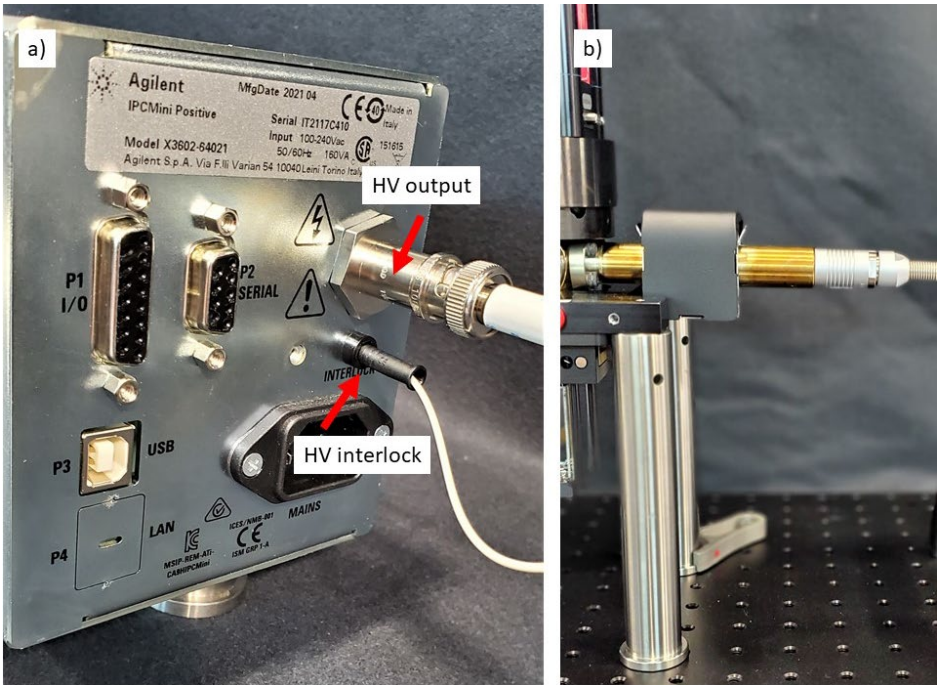


Figure 3. Connecting the HV cable to the ion pump and the controller.

When turning on the ion pump controller hold the start button for 3 seconds to engage the high voltage output (see Figure 3). Upon initial application of high voltage to the ion pump,

the current reading on the ion pump controller should be in the range of tens to hundreds of nanoamps. This value should decrease off-scale (display will read “0.0e+00 A”) within a few minutes, often within one minute.

During continued, normal usage, the current reading on the ion pump controller should toggle between off-scale low and <10 nanoamps (nA). If the current reading remains above 10 nA for a prolonged period (~24 hours), contact Infleqtion immediately for troubleshooting assistance.

Using the touchscreen menu, set the pump to the value for 2 L/s ion pump installed in the device.

1. Select the Menu button on the touch screen
2. Select the pump button on the touch screen
3. Scroll down to “2 Diode” option from the list of pumps and select
4. The present setting will output 3 kV

4. *Turn on the ion pump*

WARNING!

ION PUMP PROTECTION – Read through Step 4 completely before turning on the ion pump controller.

The dispenser is electrically connected to the red and black banana jacks on the side of the mounting plate, as shown in Figure 4. As the dispenser is resistive in nature and electrically isolated from all other components, the polarity of the drive current is irrelevant. Electrical ground of the customer’s power supply should be applied to black banana plugs. This will ensure 2D getter health.

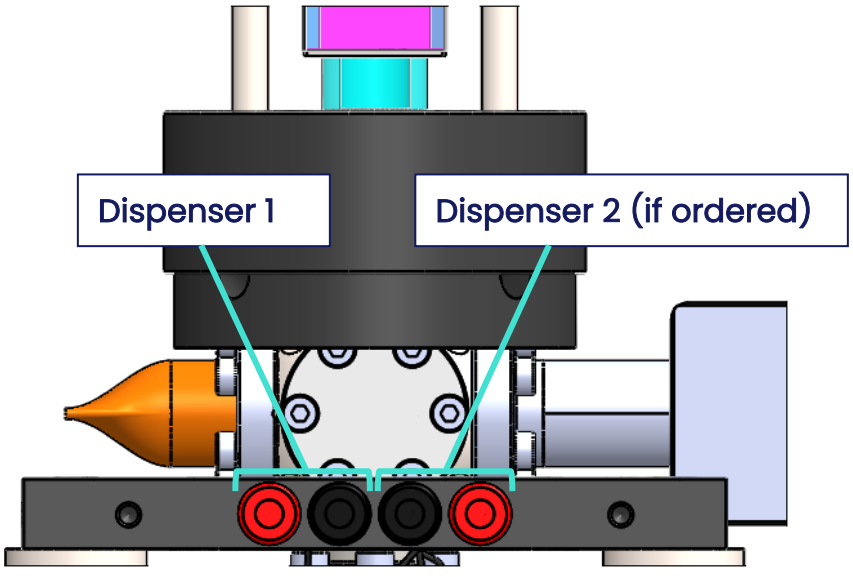


Figure 4. Dispenser connections.

To both conserve the alkali atom source and ensure maximal pumping of contaminants, it is recommended to turn off the dispenser when the system will not be used for extended periods. If the system will be used daily, it is recommended to either turn off the dispenser or reduce the dispenser current at night.

5.2 Electrical Connections

Infleqtion recommends a power supply for the dispensers of at least 20 Watt, with max 3V and 4.5A. The dispenser connections use standard banana cables (not included). Connect like colors with like; red with red and black with black. Ensure you don't run current through the getter, which uses the black connections as a common ground. While this won't hurt the system, it could off-gas material into the system.

WARNING!

ION PUMP PROTECTION – To ensure the lowest background pressures, it is recommended to always leave the ion pump controller on, even if the dispenser is not currently in use. Repeated power cycling of the ion pump controller can harm the ion pump. Please note that the ion pump controller has a protective feature that will prevent the turn on of the high voltage if vacuum is broken. If you have concerns that the unit is not under vacuum, please consult our troubleshooting

6. Normal Operation

Always ensure the ion pump is on prior to turning on the dispensers. The ion pump is designed to always be on, even when the system is sitting idle between experiments.

6.1 Creating a 2D MOT

For normal operation, drive the dispenser with a constant current between 2.7 A and 3.3 A. It may take up to 20 minutes for the dispenser to thermally stabilize once current has been applied. To ensure proper dispensing, look for atomic fluorescence induced by a resonant or near-resonant laser beam passing through the cell.

Always drive the dispenser with a power supply programmed in constant current mode with a voltage limit. The voltage limit will prevent thermal runaway of the dispenser that can prematurely deplete the atom source.

Due to variations in atom sources, the optimal dispenser current may vary between dispensers. To identify the ideal dispenser current, start with the lowest current of 3.0 A and look

WARNING!

DISPENSER PROTECTION – Under no circumstances should more than 4.5A be applied to a dispenser. Anything above this amperage may result in decreased lifespan or failure of

for laser-induced fluorescence after 20 minutes. If no fluorescence is observed, increase the current by 0.1 A, wait 20 minutes, and look again for fluorescence. Repeat this process until fluorescence is observed. If no fluorescence is observed at 3.3 A, contact Infleqtion.

To increase atom flux in the output beam, it may be desired to drive the dispenser at a higher current than the minimum needed to observe fluorescence. Typically, loading rates into a 3D MOT are used to determine a more optimal dispenser current. Note that higher dispenser currents will shorten the lifespan of the dispenser and may impact the vacuum quality in the rest of the system.

Infleqtion recommends an initial current value of 2.7 A. Always let the dispenser heat up for one hour before attempting to observe fluorescence or create a MOT.

6.2 Creating a 3D MOT

After verifying fluorescence and creating a 2D MOT, a 3D MOT can be formed. Ensure the push beam is aligned, and optics and magnetics are optimized for 3D MOT creation. Infleqtion offers optics and magnetics solutions that make creating a 3D MOT easy.

See Section 11 for Infleqtion's recommendations on the complete set of products to create a 3D MOT.

7. Troubleshooting

Issue	Solution
I don't observe fluorescence	We recommend that a vapor cell is used to verify the correct set up of your laser system if you cannot observe fluorescence. Once you are certain your laser system is correctly setup, and you are still not able to observe fluorescence, follow the steps outlined below. Apply 3.75 A to the dispenser. Let it warm up for five minutes and then point your camera directly down the cell and have it focused on the bottom of the 2D cell towards the alkaline metal dispenser. You should be able to physically see the dispenser glow without any laser light introduced. The room might need to be very dark to see it. If you verify that the dispenser glows the cell is still under vacuum. Once vacuum is confirmed it is possible that the systems alkaline metal dispenser has a lower out gassing rate than anticipated. We recommend that you try running the dispenser at 4 to 4.25 A for one hour and then repeat your fluorescence test. If you cannot observe fluorescence, please contact us at sales@Infleqtion.com for support.
I can't see a 2D MOT	• If you are using other Infleqtion products, refer to those user manuals for product-specific troubleshooting • Ensure there is current running through the dispensers • Ensure the ion pump is set to the correct settings • Ensure the 2D MOT laser setup is correct and optimized • Ensure the 2D MOT magnetic field is correct, optimized and polarity is correct • Ensure your camera type can capture a 3D MOT

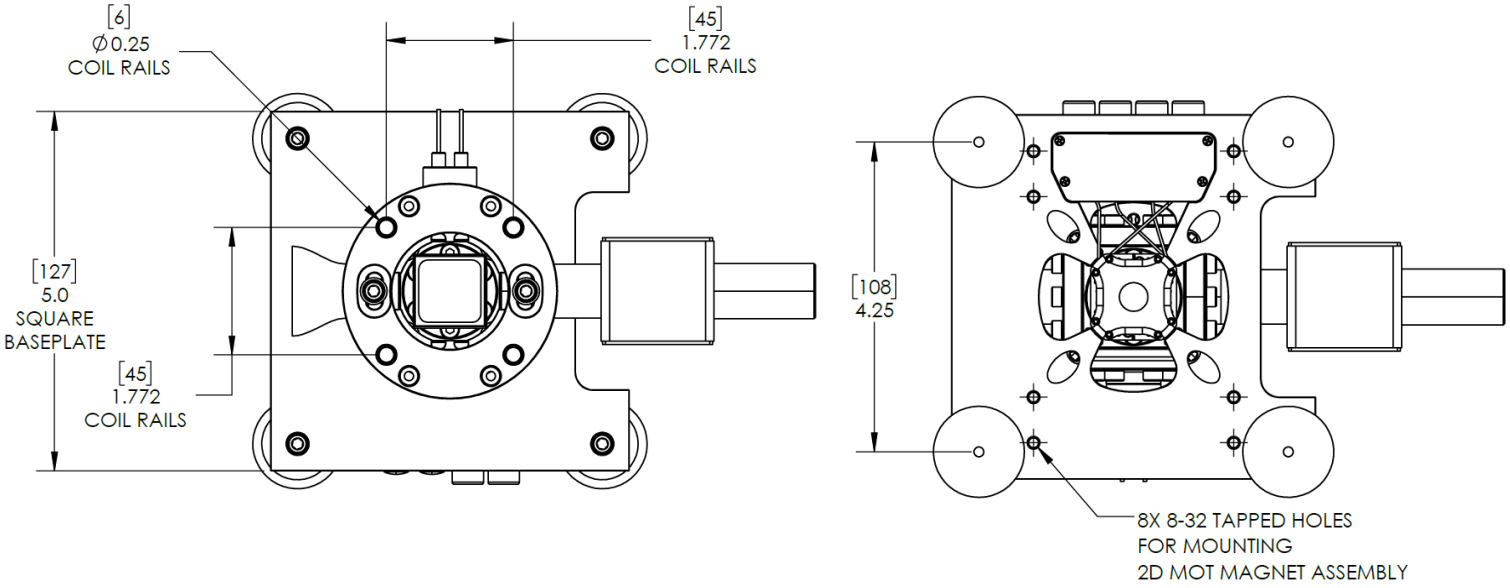
I can't see a 3D MOT	• If you are using other Infleqtion products, refer to those user manuals for product-specific troubleshooting • Verify that you can create a 2D MOT (see above) • Ensure the 3D MOT laser setup is correct and optimized • Ensure the 3D MOT coils are working properly, optimized and polarity is correct • Ensure the push beam is aligned and optimized • Ensure your camera type can capture a 3D MOT
Dispenser resistance doesn't match listed specification	• Please contact Infleqtion, as this could indicate an issue with the doubleMOT requiring service
The ion pump pressure is reading high	• Check the ion pump settings • Verify pumping current is not leakage current. Take magnets off ion pump, drive at 3kV, should say 0 amps of current, could be indicative of an issue. • Contact Infleqtion

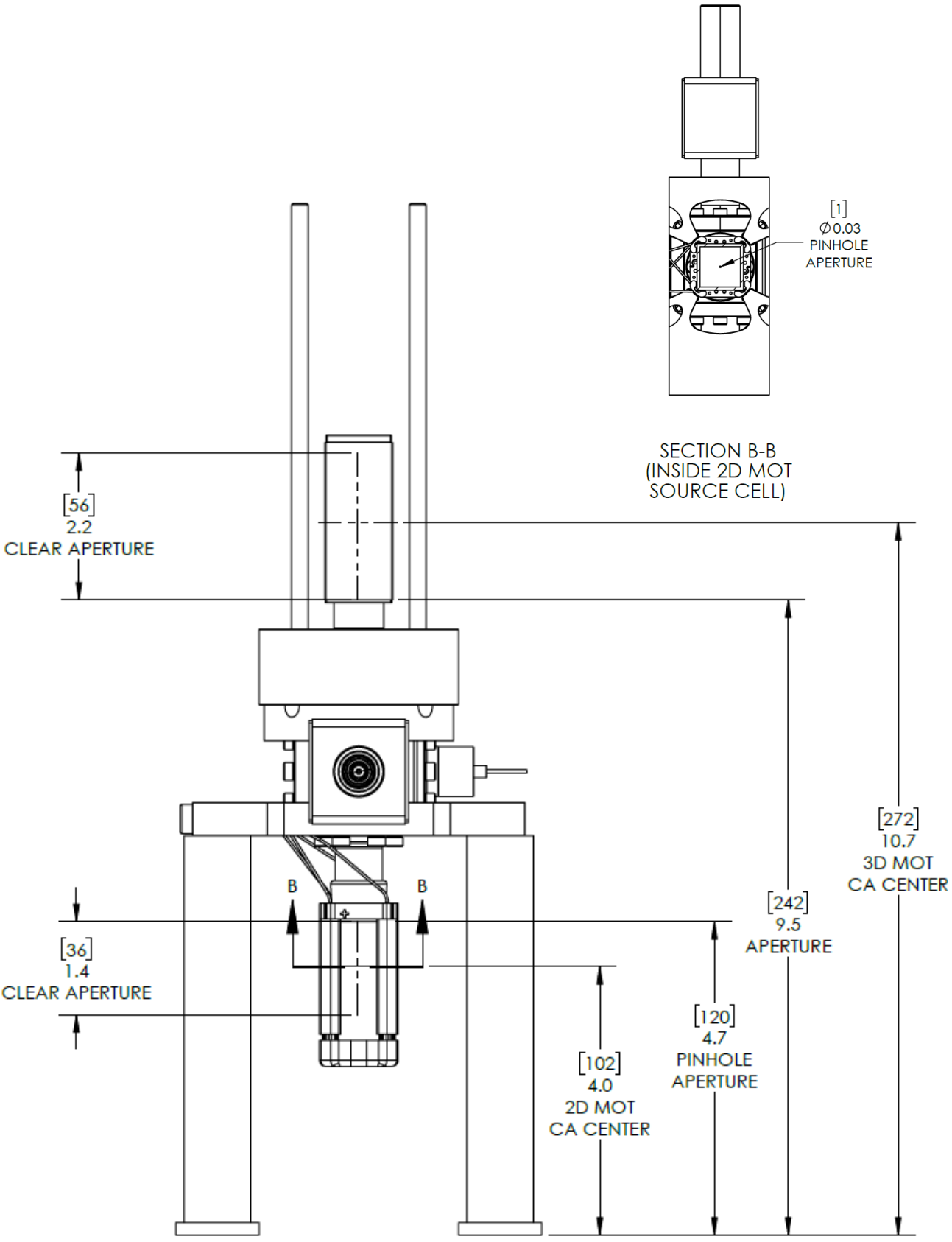
8. Warranty

Infleqtion's Terms and Conditions, including the warranty, can be found at: https://infleqtion.com/terms

9. Technical Drawings and Dimensions

Measurements in mm and [inches]

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2D MOT
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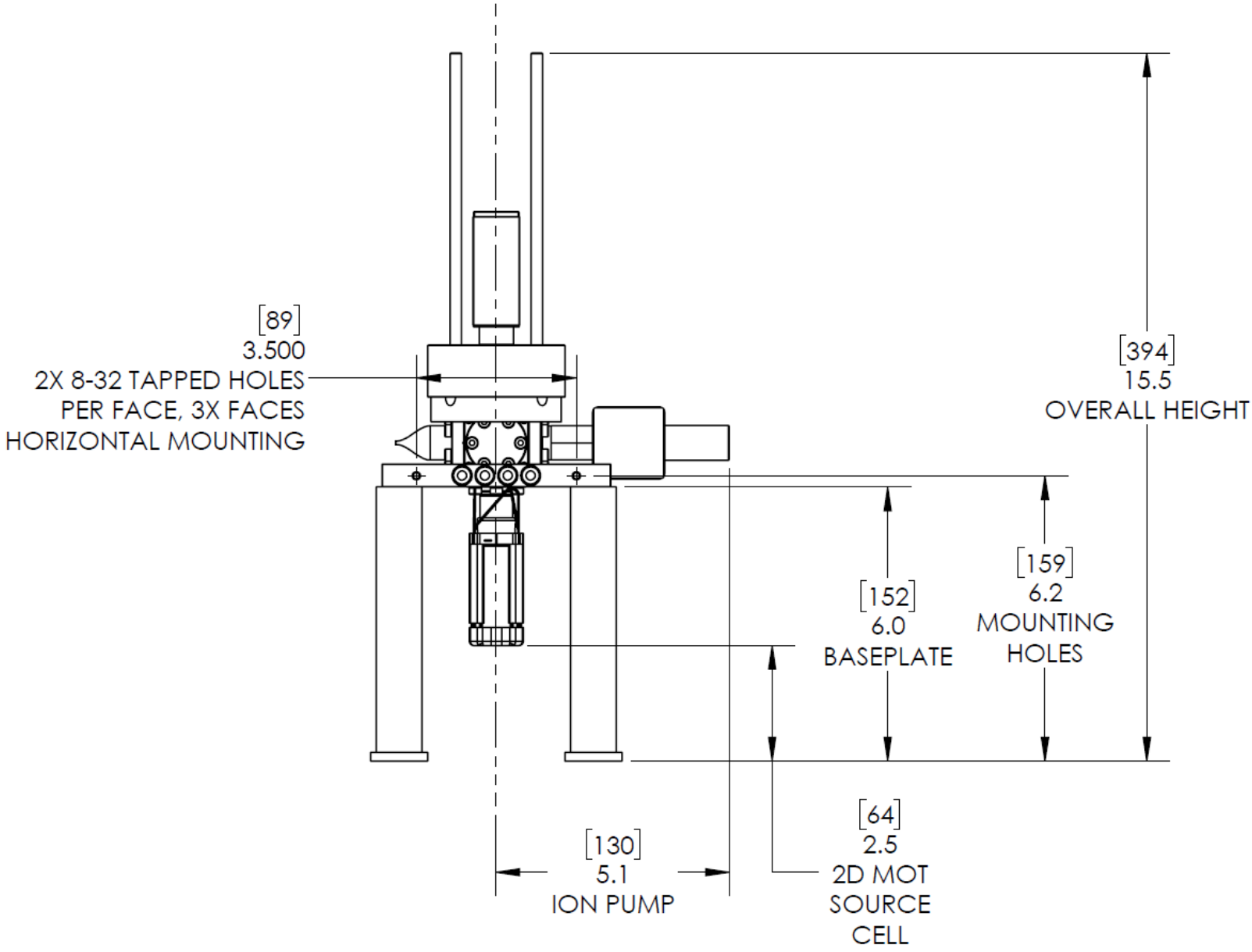
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BASEPLATE
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6.2
MOUNTING
HOLES
[130]
5.1
ION PUMP
[64]
2.5
2D MOT
SOURCE
CELL

10. References and Further Reading

1. Pati, G., Pulido, M., Fatemi, F. K., Acosta, G., & Tripathi, R. (2025). Dual-Frequency Absorption Spectroscopy in Laser-Cooled Rubidium Atoms: Theoretical Modeling and Experiment. *arXiv preprint arXiv:2508.18150*.
2. Jamieson, M. J., Weatherill, K. J., Adams, C. S., Hanley, R. K., Alves, N., & Keaveney, J. (2025). Continuous time ultra-high frequency (UHF) sensing using ultra-cold Rydberg atoms. *arXiv preprint arXiv:2504.00212*.
3. LeDesma, C., Mehling, K., Shao, J., Wilson, J. D., Axelrad, P., Nicotra, M., Anderson, D.Z. & Holland, M. (2024). Demonstration of a programmable optical lattice atom interferometer. *Physical Review Research*, *6*(4), 043120. https://arxiv.org/pdf/2305.17603

11. Appendix: Principles of Operation

The Infleqtion doubleMOT is an integrated vacuum system with optical access for trapping and cooling atoms. The system is based on a two-chamber design which simultaneously allows for large quantities of alkali atoms to be captured in the lower cell ("Source Cell") while maintaining the UHV levels that are necessary to create a Bose Einstein Condensate (BEC) in the upper cell ("Science Cell").

The system includes: an integrated alkali atom source, active (ion) and passive (getter) pumps to maintain vacuum in the chamber, and a controller for driving the ion pump. The product is sealed and shipped under vacuum ready to achieve, when properly integrated, a magneto-optical trap (MOT) in the chamber.

In conjunction with an external magnetic field gradient and laser beams, the doubleMOT can be used to produce a BEC from an alkali atom vapor. To simplify the production of a BEC, Infleqtion offers a 2D MOT magnet assembly and a TriCoil assembly to create the necessary magnetic fields.

The doubleMOT is bolted to an anodized aluminum mounting plate that is supported by four stainless steel pedestals with a height of 6" and a diameter of 1". Four steel posts ("Coil Rails") surround the Science Cell to rigidly secure the TriCoil assembly.

Ultrahigh Vacuum Cells and Ion Pump

In the source cell, atoms are trapped from a hot vapor and pre-cooled using a 2D MOT. A silicon pinhole disc at the top of the cell allows for differential pumping between the upper and lower cells. In addition, the high reflectivity of the silicon in the near infrared allows a vertically directed laser beam to be reflected off the silicon disc, thereby providing cooling in the vertical direction. Atoms pushed upward through the pinhole disc in the Source Cell are captured in the Science Cell.

The science cell is maintained at UHV levels with an Agilent VacIon ion pump with a pumping speed of 2 L/s. The ion pump is controlled by an Agilent IPCMini ion pump controller. The

controller, ion pump, and HV cable are supplied with the doubleMOT system.

Alkali Atom Dispenser

The dispenser in the Source Cell releases a vapor of alkali metal atoms (with the natural abundance of isotopes) through Joule heating when driven by a DC electrical current. The dispenser behaves as a resistive load with a resistance of approximately 0.5 Ω, although this value will change slightly depending on the dispenser's internal temperature. A current between 2.7 A and 3.3 A is recommended, although it is sometimes useful to have the current at a high setting of 3.5 to 4.0 A when first attempting to produce a MOT in a new apparatus or for verifying the ability to see atomic fluorescence with a laser system during troubleshooting. At such high currents, a MOT will form very quickly (less than one second). Very wispy MOTs from inadequately aligned laser beams or inadequate magnetic field gradients are sometimes easier to spot at high dispenser currents. It can take quite a while for the ion pump to recover the vacuum after long exposure to high dispenser currents, so it is recommended that the use of high current be kept to a minimum. The minimum threshold current measured in house is provided within the Certificate of Conformance.

Lower currents generate lower alkali vapor pressures, which in turn leads to lower background pressure and longer trap lifetimes. However, a lower alkali vapor pressure also reduces the size of the 2D MOT; the corresponding lower flux of atoms out of the 2D MOT (in the Source Cell) increases the loading time for the 3D MOT (in the Science Cell). It is up to the user to determine the current that provides the optimal trade-off between MOT loading rate and trap lifetime for their application.

Infleqtion recommends an initial current value of 2.7A. Always let the dispenser heat up for one hour before attempting to observe fluorescence or create a MOT.

2D MOT Magnet Assembly (if ordered)

The 2D MOT magnet assembly uses permanent magnets to create magnetic fields for generating a 2D MOT in the Source Cell. The assembly bolts onto the bottom of the mounting plate. When this assembly is ordered at the same time as the doubleMOT, it will be properly affixed to the mounting plate prior to shipping.

Permanent magnets are affixed into four aluminum rods that surround the Source Cell. The rods are positioned at the corners of the cell so that they do not interfere with the 2D MOT laser beams. The rods are bolted onto a frame that can be rotated several degrees about the axis of the 2D MOT.

Figure 5(b) shows a vector plot of the magnetic field generated by the 2D MOT magnet assembly. Along the two principal axes, the magnets generate field gradients typically between 32 and 38 G/cm. Actual field gradients measured with a gaussmeter are reported on the test data sheet logged in an Infleqtion database.

To ensure the highest flux of atoms from the Source Cell into the Science Cell, the 2D MOT should be positioned so that its long axis is aligned with the silicon pinhole at the top of the Source Cell. To shift the position of the 2D MOT in the two directions transverse to the cell axis, the magnet frame is bolted to a two-dimensional translation stage that is actuated via two set screws on the front and side of the stage's base as shown in Figure 5 (a).

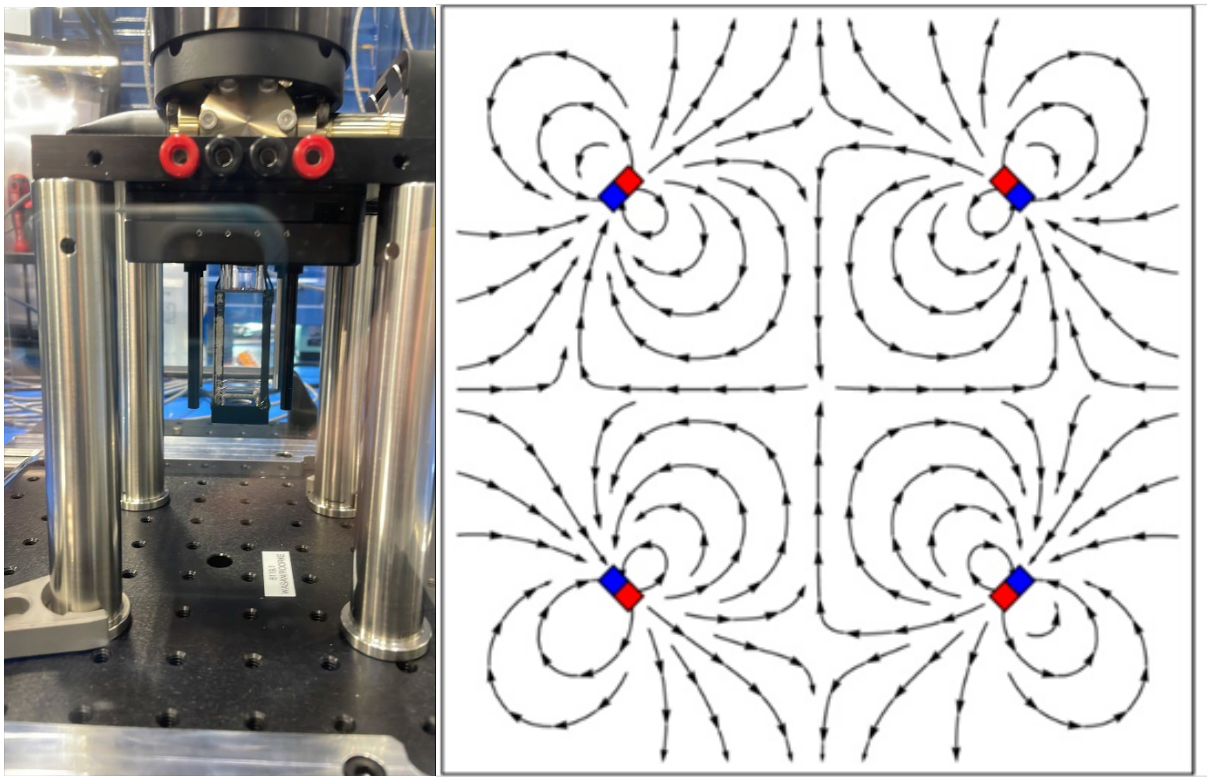

Figure 5. The 2D Mot magnet assembly (a), along with a vector plot of the magnetic field generated by the assembly.

TriCoil Assembly (if ordered)

The Tricoil assembly creates magnetic fields that are needed for a variety of functions, including magneto-optical trapping, magnetic trapping during transport, and BEC formation. When driven with electrical currents in the proper configuration, the assembly can produce either magnetic gradients (anti-Helmholtz configuration) or bias fields (Helmholtz configuration) along any of the three axes (with the proper cable and a suitable coil driver).

The TriCoil assembly consists of six rectangular coils arranged in a rectangular structure, as shown in Figure 6. The coils are affixed to an anodized aluminum frame that slides along the Coil Rails that surround the Science Cell. Electrical connections are made to the coils through a micro-D connector that is located at the base of the assembly. The assembly affixes to the coil rails using eight set screws.

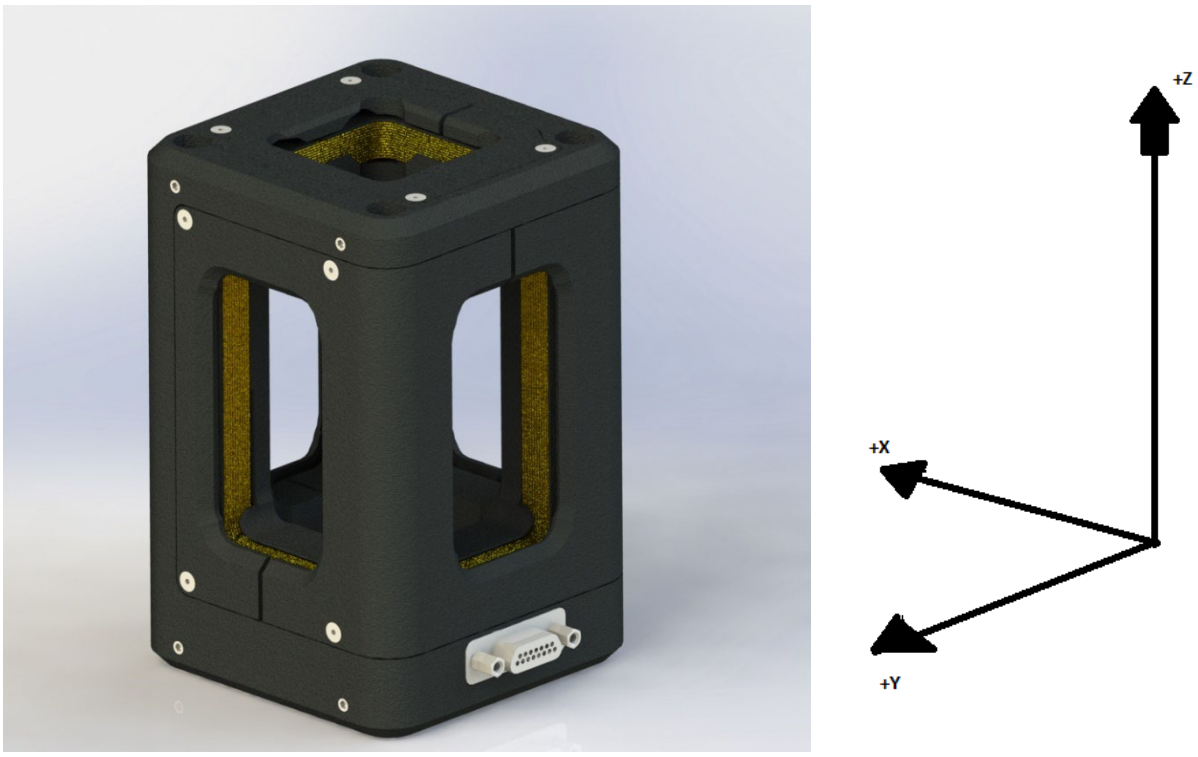

Figure 6. TriCoil assembly with coordinate system.

The Tricoil assembly includes a cable (see Figure 1) for connecting the coils to appropriate current drivers. Where applicable, the cable has a micro-D connector on one end (to the coil assembly) and a DB15 connector on the other (to the Infleqtion coil driver). In all other cases, the Tricoil is shipped with a flying leads cable, which allows for use with any coil drivers in a custom configuration.

For defining a coordinate system, it is recommended to orient the coil assembly in such a way that the side with the micro-D connector is closest to the ion pump.

Table 2 lists the pin designations that correspond to each coil. Positive currents are defined as those flowing from lower-numbered pins to higher-numbered pins. Positive currents generate magnetic fields in the positive directions of the coordinate system that is shown in Figure 3. Values for resistance and inductance are typical; actual measured values are reported on the test data sheet that is shipped with each unit.

DB15 Pin #	Coil Position	Resistance (Ω)	Inductance (mH)
1, 9	Front (X1)	2.4	0.92
2, 10	Back (X2)	2.4	0.92
3, 11	Right (Y1)	2.4	0.92
4, 12	Left (Y2)	2.4	0.92
5, 13	Bottom (Z1)	3.7	1.75
6, 14	Top (Z2)	3.7	1.75
7, 8, 15	Not Used	---	---

To produce magnetic gradients and bias fields, current must flow through both coils that are oriented along a given axis. For bias fields, current must flow in the same direction through both coils from a pair (e.g., from pin #1 to pin #9, and then from pin #2 to pin #10). By reversing the direction of the current that passes through one of the coils from a pair, a gradient is produced instead (i.e., from pin #1 to pin #9, and then from pin #10 to pin #2). For magnetic gradients and bias fields, the coils can be connected in series and driven with a single power supply. To produce a magnetic gradient whose center does not coincide with the center of the science cell, the coils from a pair must be driven with unequal currents. In this scenario, each coil from a pair must be powered by its own driver.

Each pin on the micro-D connector is rated for 3 A. Normal operation for a MOT is between 0.5 and 1.0 A. The coils will get warm during normal operation, but must not be allowed to exceed 100°C.

For further information on using the different features of the Agilent IPCmini Controller refer to the manufacture's user manual found here https://www.agilent.com/cs/library/usermanuals/public/IPCMini.PDF.

MA-00028

doubleMOT USER MANUAL

REVISION CONTROL

When any part of this procedure requires amendment, the document shall be re-issued in its entirety; requests for change shall be addressed to the document owner.

Revision	Date	Change Description	ECO	Originator(s)
Previous	2019	Document Creation		E. Salim
1.0	September 2025	• New format and new Infleqtion branding • Technical drawings updated • More emphasis on installation and use of product	S1025	C. Ward C. Williams