miniMOT V2

User Manual

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Upon receipt of your miniMOT V2 product we advise that the package is opened, and the unit is powered ON. Please refer to Section 2: Installation, page 10 for guidance.

Once this first step has been completed, we'd love to hear from you. Please share a brief email to sales@infleqtion.com to notify our team that this step has been completed successfully.

Leaving the miniMOT V2 boxed and without electrical power for an extended period of time could lead to non-optimal operation when finally powered on.

Infleqtion's standard warranty terms are 12 months from date of shipment.

For technical support, contact
sales@infleqtion.com

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1. Safety Notices

The following warnings and cautions are applicable to this device:

NOTICE – Before using the miniMOT V2 for the first time, follow the instructions in Section 4.1 “Unpacking the miniMOT V2” to ensure the system is functioning properly. If the miniMOT V2 is not functioning properly, contact Infleqtion at sales@infleqtion.com.

SHOCK WARNING - To avoid electric shock, NEVER open the enclosure without consulting Infleqtion first. Opening the enclosure without approval from Infleqtion voids the warranty.

HOT SURFACE WARNING – If used with Infleqtion’s miniMOT coils (MOT Coils), avoid physically touching the coils as they can reach 60^{o}C under normal operating conditions.

2. Package Contents

Upon receiving the miniMOT V2, please inspect the packaging for damage. If the packaging shows signs of damage or excessive shock, notify the shipping company and then contact Infleqtion or your local sales representative. The packaging materials should be stored in a safe location for possible re-use, per the instructions of the shipping company.

The package contains the following items:

- A miniMOT V2 (with integrated vacuum cell)
- An AC/DC power adapter and power cord
- Anti-Helmholtz pair of magnetic field coils
- User Manual (this document)

Note: The magnetic field coils are mounted to the miniMOT V2 prior to shipping.

If any of these items are missing, please contact Infleqtion at sales@infleqtion.com and include the associated quote, purchase order and sales order numbers.

Table 1 miniMOT V2 System Specification

Parameter	Conditions	Min	Typ.	Max	Unit
External Dimensions	h × w × d		149.1 × 119.4 × 298.5		mm
Nominal Cell Height	At cell center		88.9		mm
Weight			3.2	5	kg
Electrical:					
Single phase					
AC Power Supply Input Voltage			100-240		V
AC Power Supply Input Power		20		<60	W
AC Power Supply Input Frequency			50 - 60		Hz
DC Power Supply Output Voltage		11.8	12	12.6	V
DC Power Supply Output Current			<2	5.0	A
Instrument Load Current	Dispenser **Off** Coil Current = 0.5A HV supply On		0.6		A
Instrument Load Current	Dispenser **On** = 4A Coil Current=1A HV Supply On		1.7		A
Ion Pump Current		<200		1000	nA
Vacuum Quality with No Rb/Cs Load			<10		nTorr
Residual Magnetic Field from Ion Pump	At cell center		<0.5		G
***Clear Aperture**					
Sides of Cell	h x w	45 x 10		54 x 19	mm^2
End of Cell	Ø	8		10	mm
Alkali Metal Source **Rubidium** **Cesium**					
Dispenser operating Current		0	2.75 - 3.75	4	A
Magnetic Coil Current		-1		1	A
Magnetic Field Gradient (along coil axis)			13 – 14		G/(A-cm)

**Specific to Infleqtion Part Number CCF202065C16NB-1, if a different cell has been ordered, refer to the datasheet for that cell*

3. Description

The miniMOT V2 is an integrated vacuum system with optical access for trapping and cooling atoms. The system includes an integrated atomic source for rubidium (Rb) or cesium (Cs) atoms, ion pump and getter pump to maintain vacuum in the chamber, and electronics for driving the vacuum pumps (ion and getter), atomic source, and a pair of magnetic coils (MOT Coils) if ordered. The product is sealed and shipped under vacuum ready to achieve, when properly integrated with the required laser sources, a rubidium or cesium magneto-optical trap (MOT).

The miniMOT V2 consists of:

- Ultrahigh vacuum (UHV) glass cell
- Ion pump
- Passive getter pump
- Alkali metal dispenser (Rb or Cs)
- Electronics to drive the ion pump, the dispenser, and the magnet coils (if ordered)

In conjunction with an external magnetic field gradient and laser beam(s), the miniMOT V2 can be used to produce a three-dimensional (3D) magneto-optical trap from an alkali metal vapor of Rb atoms or Cs atoms. The vapor of atoms is created by running current through the dispenser. To simplify the production of a 3D MOT, Infleqtion offers an anti-Helmholtz coil pair (MOT Coils) to create the required magnetic fields, as well as an opto-mechanical Physics Platform (CP3780 for Rb or CP3852 for Cs) for generating a 3D MOT.

Note: Infleqtion does not guarantee MOT creation or product performance when custom magnet coil assemblies are used in conjunction with the miniMOT V2.

The selection of the UHV glass cell is determined at the time of order for a given miniMOT V2 configuration and cannot be changed once the unit is assembled. Several options for UHV glass cells that can be used the miniMOT V2 are highlighted in Table 2.

Table 2. Compatible Glass Cell Options for the miniMOT V2.

UHV Glass Cell	AR Coating Type	Rb Atom Source	Cs Atom Source
2cm Thin-walled cell	Uncoated	CMMR0001	CMMC0001
2cm AR Coated Cells	Uncoated	CMMR0005N	CMMC0005N
	H- coating	CMMR0005H	CMMC0005H
	K- coating	CMMR0005K	CMMC0005K
High-NA Imaging Cells	Uncoated	CMMR0003N	CMMC0003N
	H- coating	CMMR0003H	CMMC0003H
	K- coating	CMMR0003K	CMMC0003K

Figure 1: miniMOT V2 overview diagram showing all key product features

Note: The USB and SMB ports are for future use and are not currently available for use in the initial product release. They will become available to users in a future product upgrade in 2023.

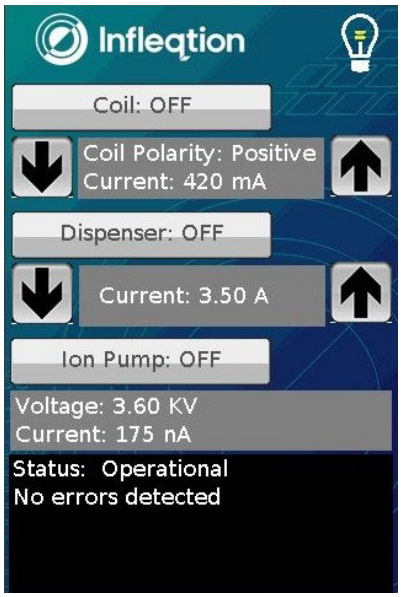


Figure 2. Example of information displayed on the miniMOT V2 touch screen under normal operating conditions.

Table 3. Functionality of the LCD display.

	Name	Function
1	*LCD Display*	The LCD display is a touch screen and allows controlling all the miniMOT V2 functionality through the screen. The brightness of the LCD display has 3 levels and can be toggled between them by touching the light bulb in the upper right corner of the LCD.
2	*Coil Current Control*	Adjusts the magnitude of the coil current between 0 and 1 A. The up and down arrows allow setting the current higher or lower.
3	*Coil Current Indicator*	Coil “OFF” or “ON” is displayed.
4	*Coil On/Off/Polarity Control*	Touching the “Coil Polarity: Pos” toggles between negative and positive current flow. When the current in the coil is off, it will be displayed as, “Coil: OFF” After touching on the text, it will toggle to show “Coil: ON”
5	*Ion Pump Indicator*	Ion Pump indicator “OFF” or “ON” is displayed. Typical current levels are < 200nA.
6	*Ion Pump On/Off Control*	When the display shows “Ion Pump: ON” the pump is turned on to 3.6kV. Touching the text will toggle the ion pump off and will show the text, “Ion Pump: OFF”
8	*Dispenser Current Control*	Adjusts the dispenser current between 0 and 4 A. The up and down arrows allow setting the current higher or lower.
9	*Dispenser Indicator*	Illuminates bright green when current flows through the dispenser.
10	*Dispenser On/Off Control*	When the dispenser is off, the LCD text shows, “Dispenser: OFF” After touching this text, the screen toggles to display, “Dispenser: ON”

4. Installation

a. miniMOT V2 Quick Start Guide

Unpacking

Upon delivery, inspect the miniMOT V2 and the surrounding packaging and unpack the unit from the box. If you have any questions, contact Infleqtion at sales@infleqtion.com.

Once you have confirmed that all products ordered are present, proceed to System Start.

System Start

To start the miniMOT V2 for the first time, the following steps must be completed in order:

1. Affix the miniMOT V2 securely to a surface before plugging in the power.
2. Plug in the power supply.
3. Locate the power button as shown in Figure 1 and turn on the miniMOT V2.
4. Wait for the main touch screen to display.
5. Locate the ion pump button on the touch screen.
6. Turn on the ion pump and observe the voltage rise to 3.6 kV and the current rise to some non-zero (nA) value.

Within approximately 30 to 60 seconds, you should observe the current value drop to less than 100 nA. This indicates that the ion pump is functioning properly, and the device is under vacuum.

*If pump down takes more than 10 minutes, please contact us at sales@infleqtion.com.

Dispenser Validation

A final fluorescence test of the miniMOT V2 was completed prior to shipping the unit. It is useful to repeat this test upon receipt of the unit to provide additional validation of the system's vacuum integrity and dispenser connection. This test assumes that you have a laser system that provides laser light resonant with one of the major transitions used for your atom (e.g., 780.2 nm or 852 nm for the D2 transitions of rubidium and cesium respectively).

Direct/guide a laser beam of 1-3 mW of power with a beam diameter of 1-3 mm and through the glass cell while scanning the laser frequency over a known, strong atomic/electronic transition. Setup an infrared sensitive camera or infrared viewer to observe fluorescence. A darkened room is advised for optimal viewing of NIR fluorescence.

Turn on the dispenser. The touch screen button above the ion pump button activates the dispenser. The arrow buttons below the dispenser button allow you to adjust the dispenser current. The *minimum* current at which you should see fluorescence is 2.75 A and the maximum current at which you should see fluorescence is 3.75 A.

Set the dispenser current to the value indicated on the unit's datasheet provided with the unit when shipped and wait 30 minutes before checking for fluorescence. If you do not observe fluorescence, increase the dispenser current by 0.2 A and wait an additional 30 minutes to check for fluorescence. Continue this process until fluorescence is observed, but do not exceed 3.75 A.

The 30-minute intervals allow the cell to be "seasoned" with atomic vapor.

Coil Validation and Final System Checks

Set miniMOT V2 coil current to 1.0 A and confirm that rear panel display shows 1 Amp actual output. Switch polarity and verify output at -1.0 A.

The corresponding orientation of the magnetic field is displayed on Figure 3. A compass can be used to verify the proper switching of the orientation with polarity.

If you see any error message at the bottom of the display screen, immediately contact Infleqtion at sales@infleqtion.com.

b. Turning the miniMOT V2 On (daily operation)

1. Connect the power cable to the *Power Input* jack on the rear panel of the miniMOT V2.
2. Plug the power adapter into an AC supply per the specification in Table 1. If a different power supply is used, it must match the requirements in Table 1. Improper use will void the warranty.
3. Using the display, set the *Ion Pump On/Off* to the "ON" state. Wait for the *Ion Pump Indicator* to turn bright green.
4. Using the display, set the *Dispenser On/Off* to the "ON" state.
5. Using the display, set the *Dispenser Current* to between 2.5 A to 3.5 A for normal operation. Higher currents may be required to load the cell with rubidium atoms/vapor if the dispenser has been set to OFF for extended periods (see Principles of Operation for more information).

6. To run current through the coils, using the display, set the *Coil On/Off* to the "ON" state. Then set the *Coil On/Off/Polarity* to either "pos" or "neg" direction (depending on laser polarization). Set the coil current recommend starting value of 0.5A, although MOTs can be easily created with currents as low as 0.2 A and as high as 1.0A depending on the magnetic environment in the near vicinity of the product.

c. Turning the miniMOT V2 Off

1. When not in use, the *Dispenser On/Off* button should put into the OFF state using the touchscreen display.
2. Turn off the coils by moving the *Coil On/Off/Polarity* to the OFF state using the touchscreen display.
3. It is **recommended to leave the ion pump ON at all times**, even over many months. This will maintain the vacuum and there is no wear and tear on the ion pump.

5. Principles of Operation

At the heart of the miniMOT V2 is a permanently sealed ultrahigh vacuum (UHV) glass cell. A small, 0.4 liters per second, ion pump maintains the ultrahigh vacuum, while a dispenser supplies rubidium (Rb) or cesium (Cs) atoms to the cell.

a. The Ultrahigh Vacuum Cell and Ion Pump

The ion pump incorporates a pair of rare-earth magnets. Although these magnets are shielded, there remains a small residual magnetic field. In the MOT region (i.e., the center of the glass cell), this residual field is less than the Earth's field. For most users this will have no impact.

The ion pump always operates at a fixed voltage of 3.6 kV. To avoid electrical shock, it is recommended that users **do not open the enclosure** without consulting Infleqtion. Opening the enclosure voids the product warranty.

WARNING!

DO NOT OPEN THE MINIMOT – To avoid shock, NEVER open the enclosure without consulting Infleqtion. Opening the enclosure without approval from Infleqtion will void the warranty per our Terms & Conditions shared with our quote.

When the ion pump is "ON" and the current is greater than 200 nA, then the dispenser cannot be turned "ON". In addition, if the dispenser is set to "ON" and the ion pump current goes above

200 nA, then the dispenser automatically shuts “OFF”. Both cases are to protect the ion pump and the cell from experiencing too much dispensed atom vapor.

Note that the current-to-pressure conversion for ion pumps is almost always made with reference to nitrogen pressure. The actual value of this conversion depends upon the gas species being pumped.

When the unit is first switched to the “ON” state, the *Ion Pump Current will be 100s of nA and pump down to 0 nA* in a timeframe of a few seconds to approximately 60 seconds. The actual time will (1) **depend on the length of time the ion pump has been inactive**, (2) the recent rubidium load, and (3) the thermal history of the environment the unit has been used in.

An ion pump can have a difficult time starting when the vacuum pressure is too low because it operates through an electrical discharge, and to create that discharge there must be sufficiently small, yet finite pressure. This condition can arise if the ion pump has been active for considerable time, but the rubidium dispenser has not.

If the ion pump is deactivated and then turned on again shortly afterwards, the *Ion Pump Indicator* can display green indicating no current flowing through the ion pump because it hasn’t started. When the pressure rises sufficiently, either because of background outgassing or dispenser activation, the Message Window on the display will show one of two possible problems detailed in Table 4 below. The following lists various warning and error messages and notes about the conditions.

Table 4. Possible Warning and Error messages

Warning/Error Message	Notes
Dispenser not enabled, ion pump overcurrent.	Normal operation can produce current levels above 200 nA. The dispenser is automatically turned “OFF” to protect the ion pump and the glass cell.
System is not calibrated.	Return to factory for calibration.

The ion pump current can stay above 200 nA if the glass cell is overloaded with rubidium (or cesium) or has been turned “OFF” for several months.

Nominal dispenser current for MOT generation: 2.75-3.75A

To prolong the life of the dispenser and ion pump, the user should drive the dispenser at the minimum threshold dispensing current.

If the ion pump current reads greater than 200 nA for an extended time, this could indicate an issue with the vacuum. In this situation, please contact Infleqtion at sales@infleqtion.com.

b. The Alkali Metal Dispenser

The dispenser releases rubidium or cesium with the natural abundance of isotopes: 72% ^{85}Rb and 28% ^{87}Rb or 100% ^{133}Cs.

It does so by heating the dispenser element with an electrical current. A safety feature in the miniMOT V2 prevents current from flowing to the dispenser unless the ion pump is “ON”. Dispenser current can be adjusted from 0 A to 4 A.

For most users, a dispenser current in the range of 2.75 to 3.75 A is required to release enough Rb or Cs atoms without overloading the ion pump.

In a new vacuum chamber, the chamber walls act as a pump for the alkali atoms. This means that it can take several hours (>5 hours in some cases) of operation of the dispenser before a significant amount of alkali (Rb, Cs) atoms are visible in the vacuum chamber. We refer to this as “seasoning” of the vacuum. It is normal and should not be cause for concern.

6. Accessories

a. Magnetic Field Coils

The miniMOT V2 can be purchased with Infleqtion’s standard magnet Coils (MOT Coils) This assembly, if ordered, comprises of a pair of circular magnetic field coils that are positioned on the top and bottom of the miniMOT V2 glass cell as shown in Figure 2. The coils are wired in series in opposing senses, thereby forming an anti-Helmholtz pair. When driven with a DC current, the coils generate a magnetic quadrupole field whose center coincides with the spatial center of the glass cell. Please see Figure 3 below.

The DC resistance of the two coils in series is approximately 8 Ω.

The total inductance of the coils in series in a quadrupole configuration is approximately 5-6 milli Henri (mH).

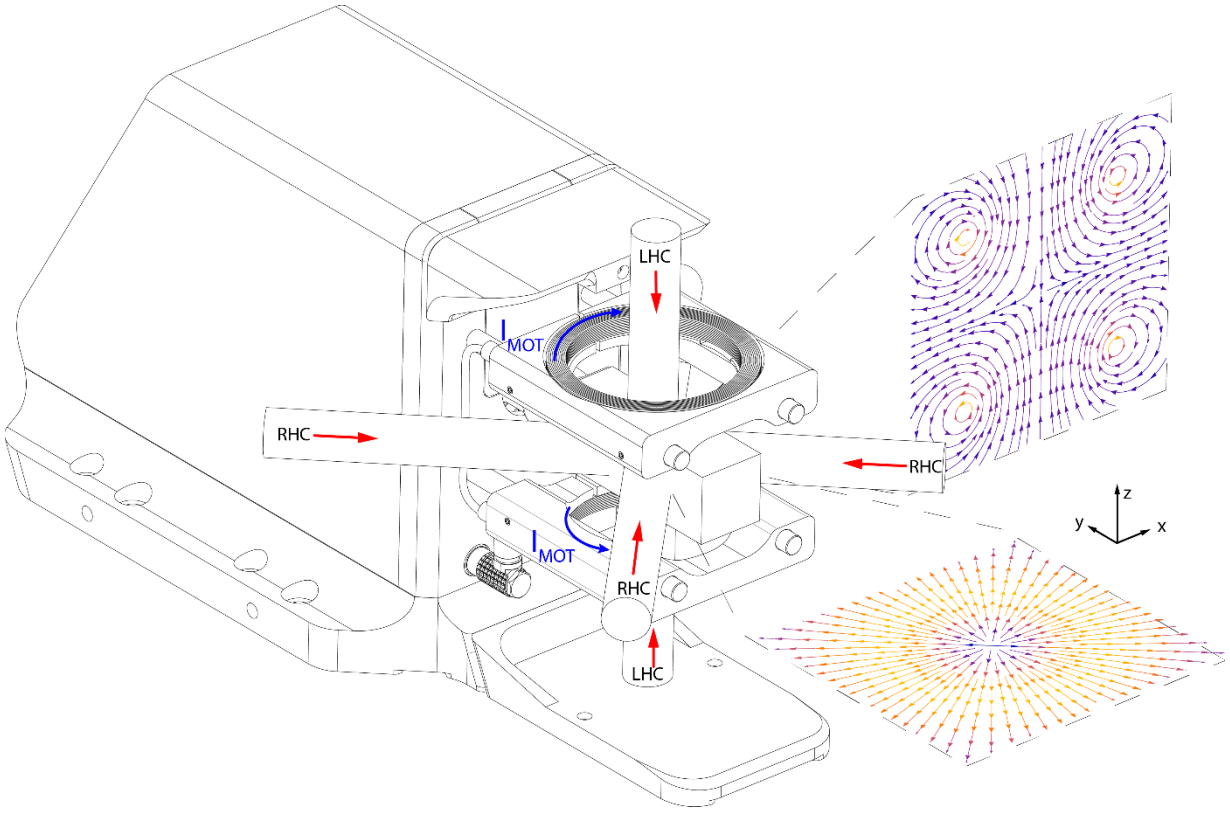
The coils electrically connect to the miniMOT V2 panel via a 2-pin cable. To flow current through the coils, use *the Coil On/Off/Polarity* controls on the LCD screen. No current flows when the LCD screen shows “Coil OFF”. Current flows when the user touches the “Coil OFF” and then it toggles to show “Coil ON”. The user can then touch/press the up and down arrows to select the current level. The polarity or direction of the current can be changed to be “pos” for positive or “neg” for negative. When *Coil polarity pos*, is shown then a current flows through the top coil first, and then the bottom coil second. When *Coil polarity neg*, is shown then current flows through the coils in the opposite way, i.e., through the bottom coil first and then the top coil. The corresponding orientation of the magnetic field is shown in Figure 3.

The user can set the coil current to any value between 0 A and 1.0 A. Typically, 0.5-0.7 A will produce a MOT.

For both current polarities, the coils generate a magnetic quadrupole gradient field of up to 13.5 G/(A-cm).

However, only one polarity will generate a MOT, and that polarity depends on the laser polarization, which is determined by the user and the specific laser used. When this polarization is known, one can calculate which direction current should flow through the coils to produce a MOT.

Figure 3. Three-dimensional plot of the magnetic field for miniMOT, shown with positive polarity through the coils. Correct optical polarization states are shown for the MOT beams, where RHC and LHC indicate right-hand circular and left-hand circular polarization respectively. In the case of negative polarity through the coils the magnetic field vector directions would reverse, and the handedness of the optical fields would also flip.



7. Troubleshooting

If the *Ion Pump Indicator* current remains high (>200nA) for more than 24 hours while the dispenser is off, a failed vacuum is likely. This condition is to be avoided when the user operates the product.

If the *Ion Pump Indicator* current is < 200nA, and you are unable to observe a MOT, the problem is likely associated with the external optics and photonics used (e.g., laser polarizations, magnetic field orientation, etc.) than with the miniMOT V2.

There are a few checks that can be performed to verify the proper operation of the miniMOT V2 and these are addressed in this section.

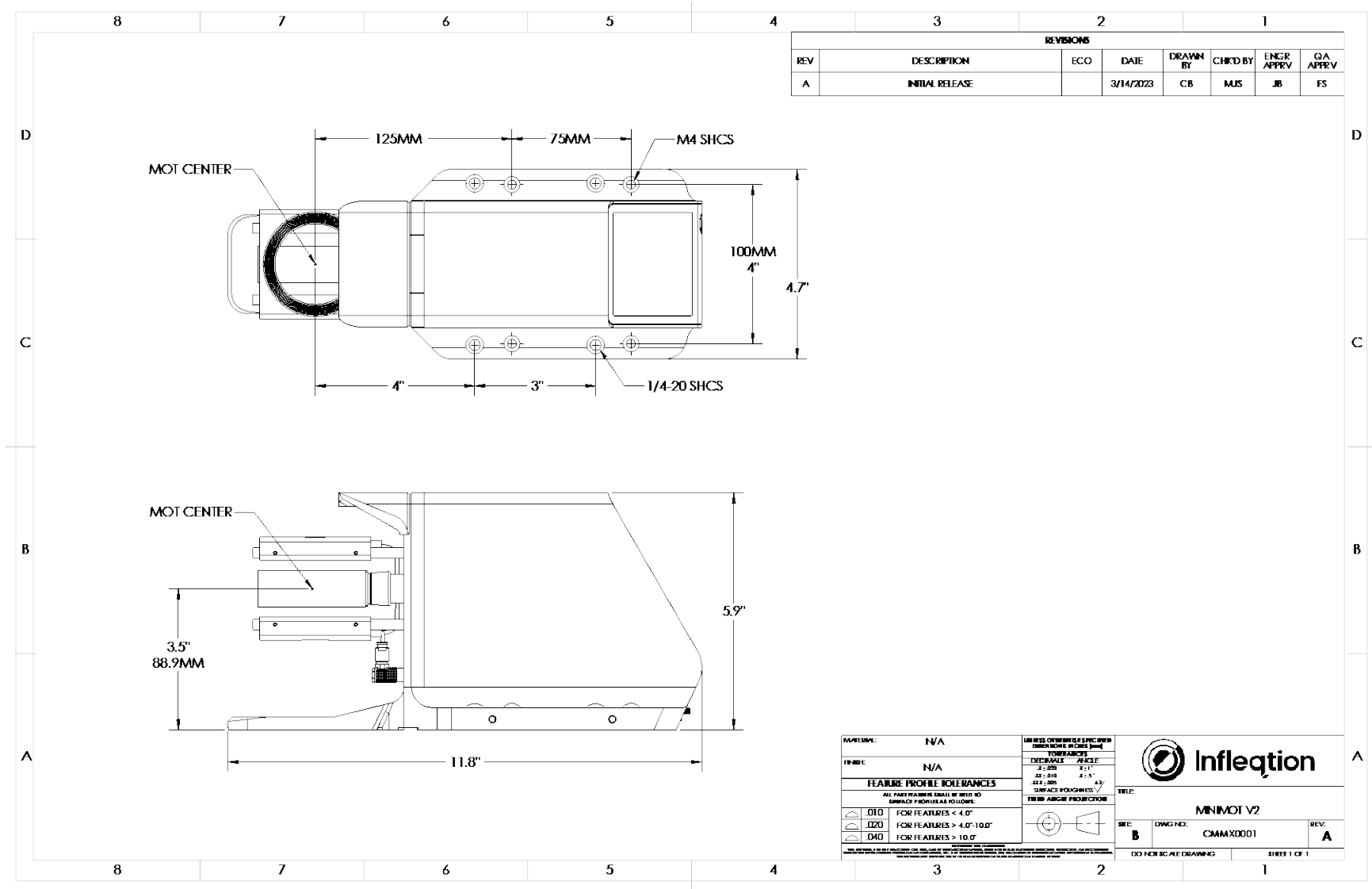
a. Nonfunctioning Indicators

Check the power connections and ensure *the Ion Pump On/Off* is in the "ON" state. If the *Ion Pump Indicator* remains dark green, unplug the power connector from the miniMOT *Power Input* and measure the DC voltage across the coaxial connections. It should read 12 VDC. If it does not, check that there is power at the outlet. If power is supplied to the miniMOT V2 but the indicators remain inoperative, or if the power module has failed, contact Infleqtion for assistance.

b. Ion Pump Indicator Remains High (>200nA) For Longer Than 24 Hours

Note the appearance of the glass cell, in particular look for white, blue, purple, or silver films or coatings on the walls. Contact Infleqtion for assistance at sales@infleqtion.com.

8. Technical Drawings and Dimensions



9. Terms and Conditions of Sale and Service

All Infleqtion hardware, software, products, services as well as all included materials and data are governed by the Terms and Conditions of Sale and Service found at https://www.infleqtion.com/standard-purchase-order-terms-and-conditions-1.

Per these terms and conditions, the warranty period starts upon shipment of the product. Therefore, it is highly recommended to unpack, inspect, and test the miniMOT V2 unit immediately.