Z-Coil Assembly User's Manual

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Table of Contents

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1. Description

1.1 Overview

The Z-coil and RF loop assembly consists of a magnetic field coil used to transport atoms vertically to the atom chip in a RuBECi® cell, and a RF loop for evaporatively cooling atoms trapped with the atom chip. The two components are bolted onto a frame that slides up and down the coil rails that are shipped with every RuBECi cell (see Figure 1).

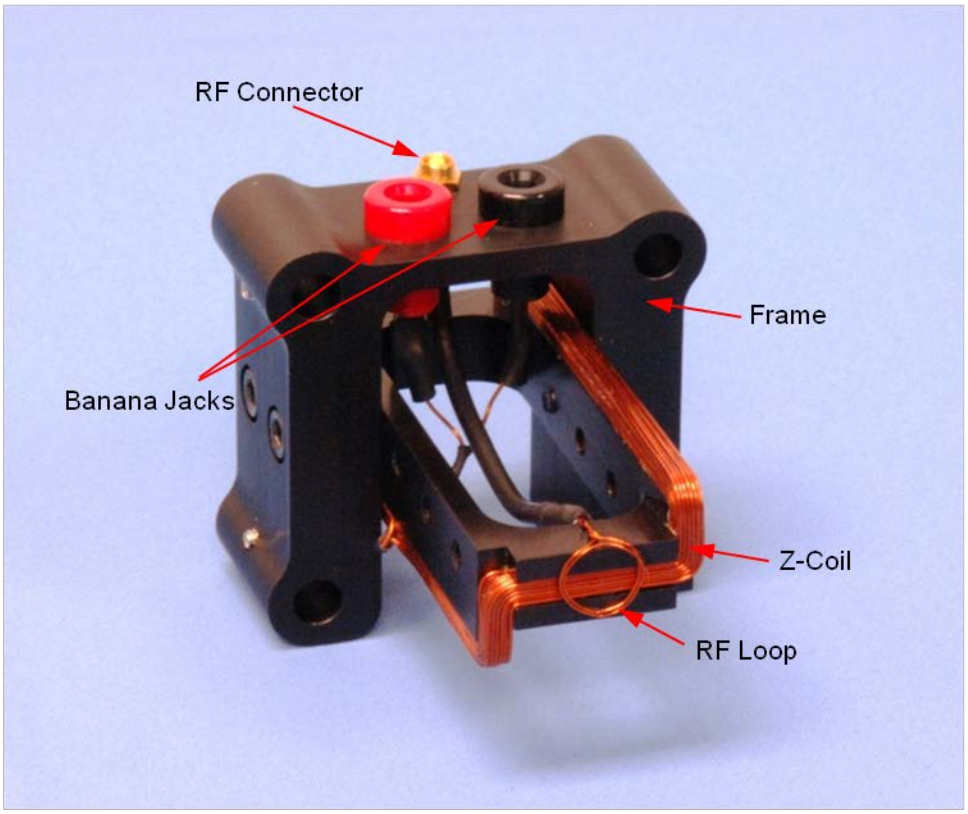

Figure 1: Photograph of the Z-coil and RF loop assembly.

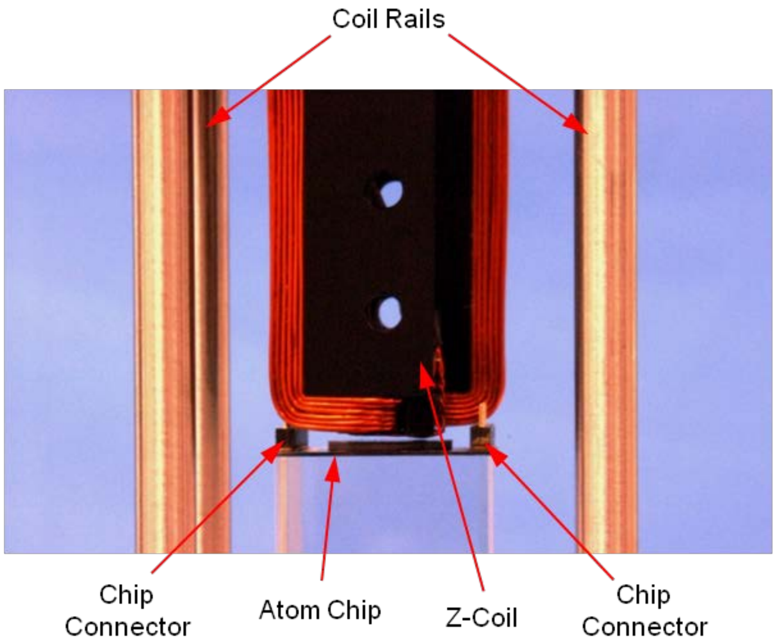

Figure 2: Photograph of the Z-coil mounted on the coil rails, and its position relative to the atom chip. Not shown are the 3D coil assembly and flex wires that connect to the atom chip.

2. Z-Coil Operation

The Z-coil consists of 36 windings of 24 AWG solid copper wire that are orientated in six layers with six windings per layer (see Figure 1). On the top and bottom, the windings are oriented in a "Z" configuration similar to the layout of the traces on the atom chip. The Z-coil is mounted so that the bottom side rests approximately 1 mm above the silicon backing disc that is affixed to the ambient side of the atom chip at the top of a RuBECi cell (see Figure 2).

2.1 Principle of Operation

The Z-coil is used to create a Ioffe-Pritchard (IP) magnetic trap 1.5 cm below the vacuum side of the atom chip, which is the approximate location of the center of the 3D MOT chamber (equivalently, this is approximately 1.7 cm below the bottom face of the mounted Z-coil). Atoms trapped in a 3D MOT in the center of the upper chamber are loaded into the IP trap by simultaneously turning off the MOT and driving the Z-coil with a current up to 20 A. Note that by itself, the Z-coil does not create a magnetic trap. To create an IP trap, a bias field of a few tens of gauss is needed. The resulting IP trap has a depth between 20 and 40 G and a minimum field of a few gauss, depending on the actual values of the Z-coil current and bias fields.

The location of the trap center below the coil scales linearly with Z-coil current. To transport the atoms vertically, th3 Z-coil current is decreased. To prevent atom sloshing during transport, the duration of the ramp should be at least 0.2 s. More details on experimentally verified current

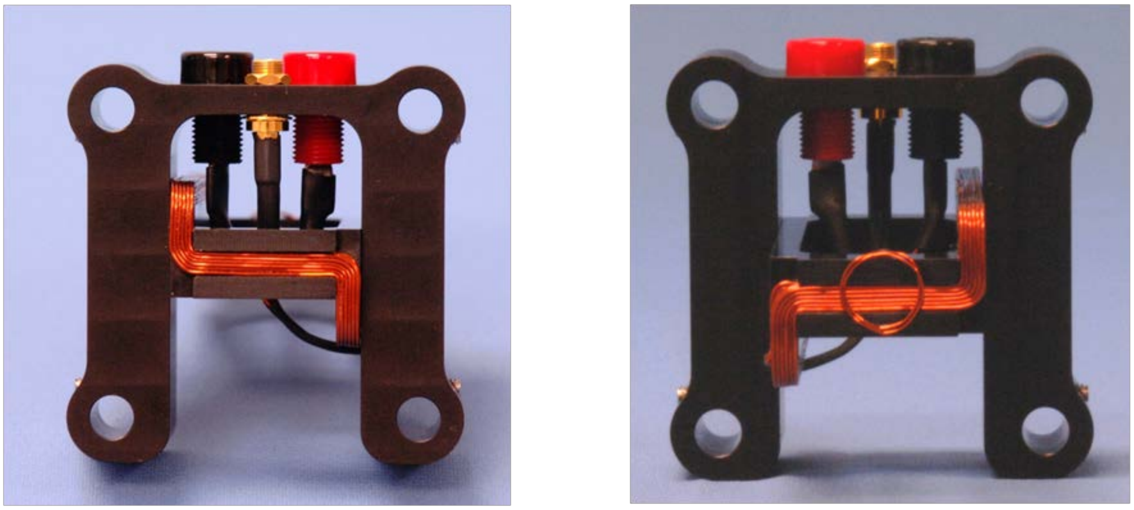

Figure 3: Top (left) and bottom (right) view of the Z-coil. The assembly can be mounted upside down to change the sense of the "Z."

ramps can be found in References [1] and [2]. These references also contain information on how to transfer the atoms from the Z-coil IP trap to the atom chip IP trap.

2.2 Z-Coil Orientation

Since the Z-coil and atom chip both use electrical conductors oriented in a "Z" configuration, a bias field is needed to create an IP trap with both the Z-coil and atom chip. To ensure that the bias field points in the same direction when transferring atoms from the Z-coil IP trap to the atom chip IP trap, the senses of the "Z" configurations should be the same (i.e. the legs of the Z-coil and atom chip Z-trap must point in the same direction). The sense of the chip Z-trap can be easily changed by running current through different legs of the chip conductors, while the sense of the Z-coil can be reversed by unbolting the Z-coil from its frame and flipping it upside-down (see Figure 3). When the sense of the Z-coil is reversed, the RF loop

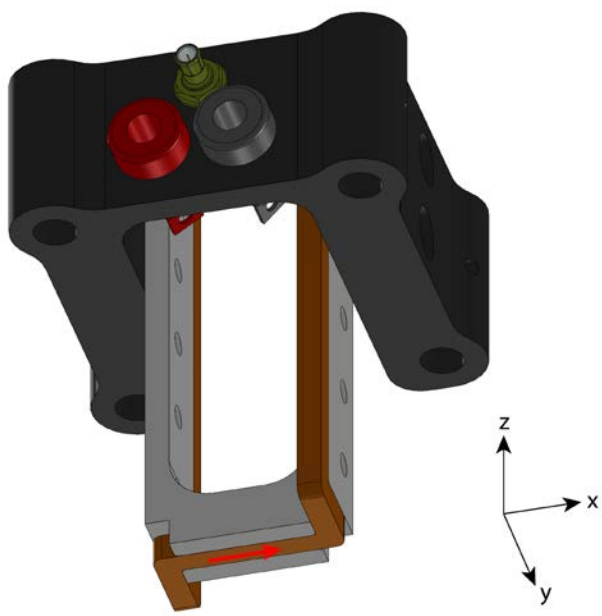

Figure 4: When mounted in the orientation shown in Figure 3, a positive current creates a magnetic field underneath the coil that points in the +y direction (away from the front of the banana jacks). For simplicity, the RF loop is not shown.

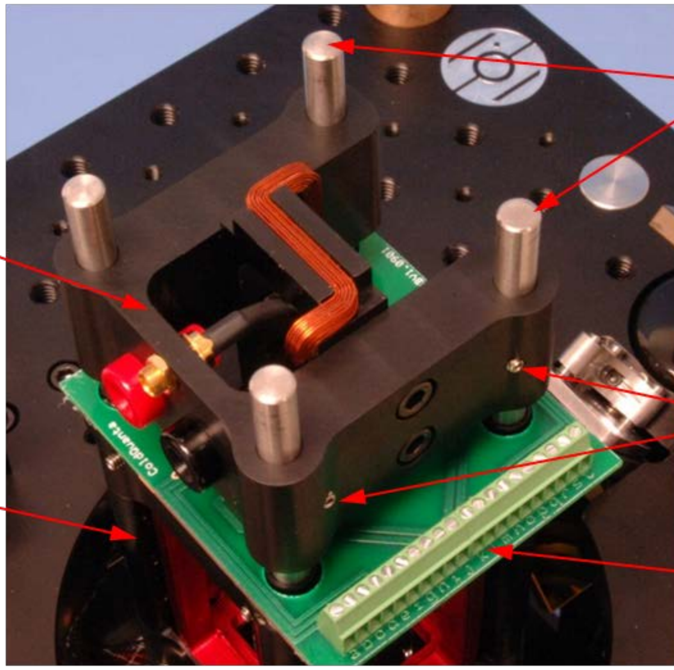

Figure 5: Top view of the installed Z-coil assembly. The assembly bolts onto the four coil rails via four set screws and rests above the breakout board and 3D coil assembly.

will need to be removed from the frame and re-affixed to the opposite end of the Z-coil. Please contact ColdQuanta for more information about this procedure.

The Z-coil is shipped in the configuration shown in Figure 3. As detailed in Figure 4, a positive current – defined as flowing from the red banana jack to the black banana jack – flows in the +x direction at the bottom-center of the coil (as indicated by the red arrow in Figure 4). Underneath the center of the coil, the magnetic field points in the +y direction; a trap is formed by adding a bias field that points primarily in the –y direction. Adding a smaller bias field in the x direction creates a IP trap.

2.3 Mounting the Assembly

The Z-coil is mounted in a frame that slides onto the four coil rails that surround the 3D MOT chamber of the RuBECi cell (see Figure 5). The assembly bolts onto the rails with four set screws, and is positioned above the 3D coil assembly and breakout board. The assembly should be bolted in place such that there is a 1 mm gap between the bottom of the Z-coil and the top of the silicon backing disc located on the ambient side of the atom chip (see Figure 2).

2.4 Driving the Z-Coil

The Z-coil has a resistance of approximately 0.7 Ω and an inductance of approximately 110 µH. To drive 20 A through the coil therefore requires a current source with a compliance voltage of at least 14 V, although a higher voltage will likely be needed to overcome resistive losses along the cable connecting the Z-coil to the current source. The Z-coil is electrically connected to the banana jacks on the mounting frame (see Figure 1).

Since the Z-coil is inductive, the maximum rate at which current can be driven through the coil is determined by Faraday's law:

$$\frac{dI}{dt} = -\frac{V}{L} \ ,$$

where the compliance voltage V is the maximum voltage applied to the coil, and L is the coil inductance. Ignoring voltage drops across the supply cables, the shortest time Δt that the coil can transition from 0 to 20 A is therefore

$$\Delta t = -\frac{L}{V}\,\Delta I \ .$$

For a compliance voltage of 15 V, $\Delta t = 200$ µs.

3. RF Loop Operation

Attached to the bottom of the assembly is a RF loop for implementing evaporative cooling of chip-trapped atoms (see Figure 1). Typically, RF frequencies between 1 and 40 MHz are used, and RF powers are typically less than 1 W (into a 50 Ω load). Frequency and power ramps that have been used to successfully create Bose-Einstein condensates can be found in References [1] and [2].

At these frequencies, the impedance of the coil is significantly less than 50 Ω. To ensure proper impedance matching, and therefore that maximum current is delivered to the loop by the RF power amplifier, we recommend that a 50 Ω resistor be inserted in series with the loop. We also recommend using a network analyzer to verify that the impedance is close to 50 Ω in the desired frequency range.

The RF loop is connected to the MCX connector on the assembly frame via an RG-174 coaxial cable (see Figure 1). A MCX cable is included with delivery of the coil for connecting the system to an RF source.

4. References

[1] Matthew B. Squires, "High repetition rate Bose-Einstein condensate production in a compact, transportable vacuum system," Ph. D. thesis, University of Colorado, Boulder (2008).

[2] D. M. Farkas, K. M. Hudek, E. A. Salim, S. R. Segal, M. B. Squires, and D. Z. Anderson, "A compact, transportable, microchip-based system for high repetition rate production of Bose-Einstein condensates," Appl. Phys. Lett. **96**, 093102 (2010).

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