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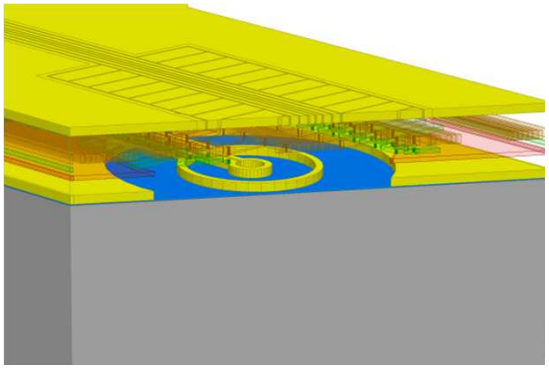

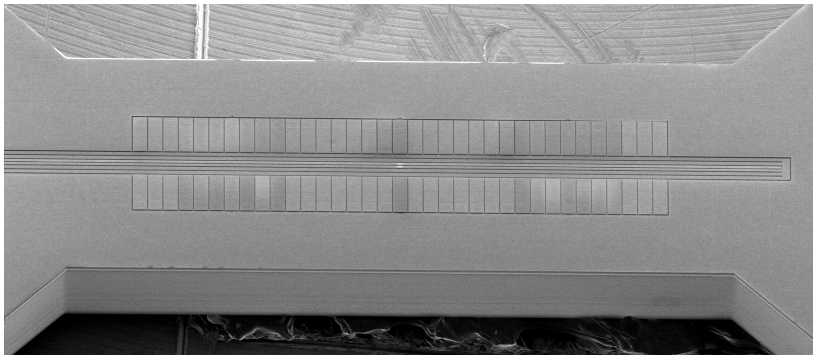

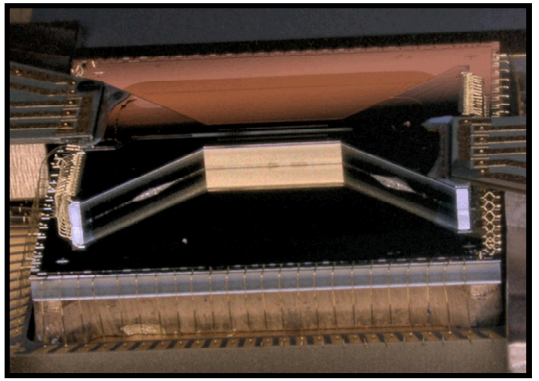

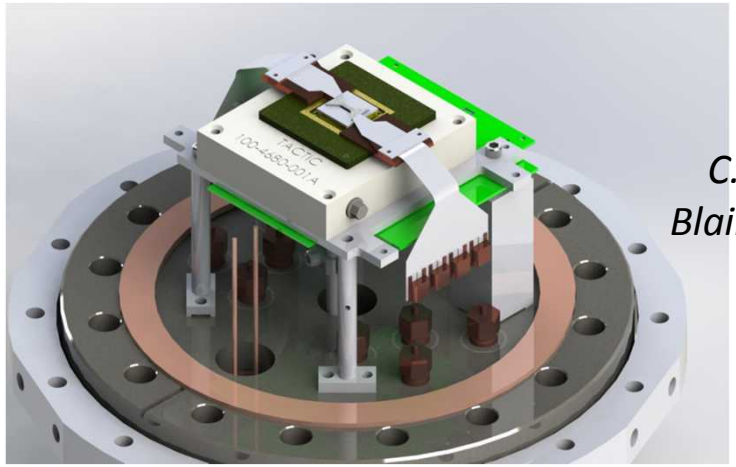

A Microfabricated Ion Trap for Microwave Induced Ion Interactions

C. D. Nordquist, C. W. Berry, J. Rembetski, A. Hollowell, P. Resnick, M. Blain, J. L. McClain J. Sterk, E. Heller, R. A. Haltli, K. M. Fortier, P. Maunz

Sandia National Laboratories

MQCO PI Meeting, June 24, 2015

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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Microwave Integrated Trap
Introduction

Goal: A Surface Microfabricated Ion Trap with Integrated Microwave Circuitry For Microwave Induced Yb^+ Interactions.

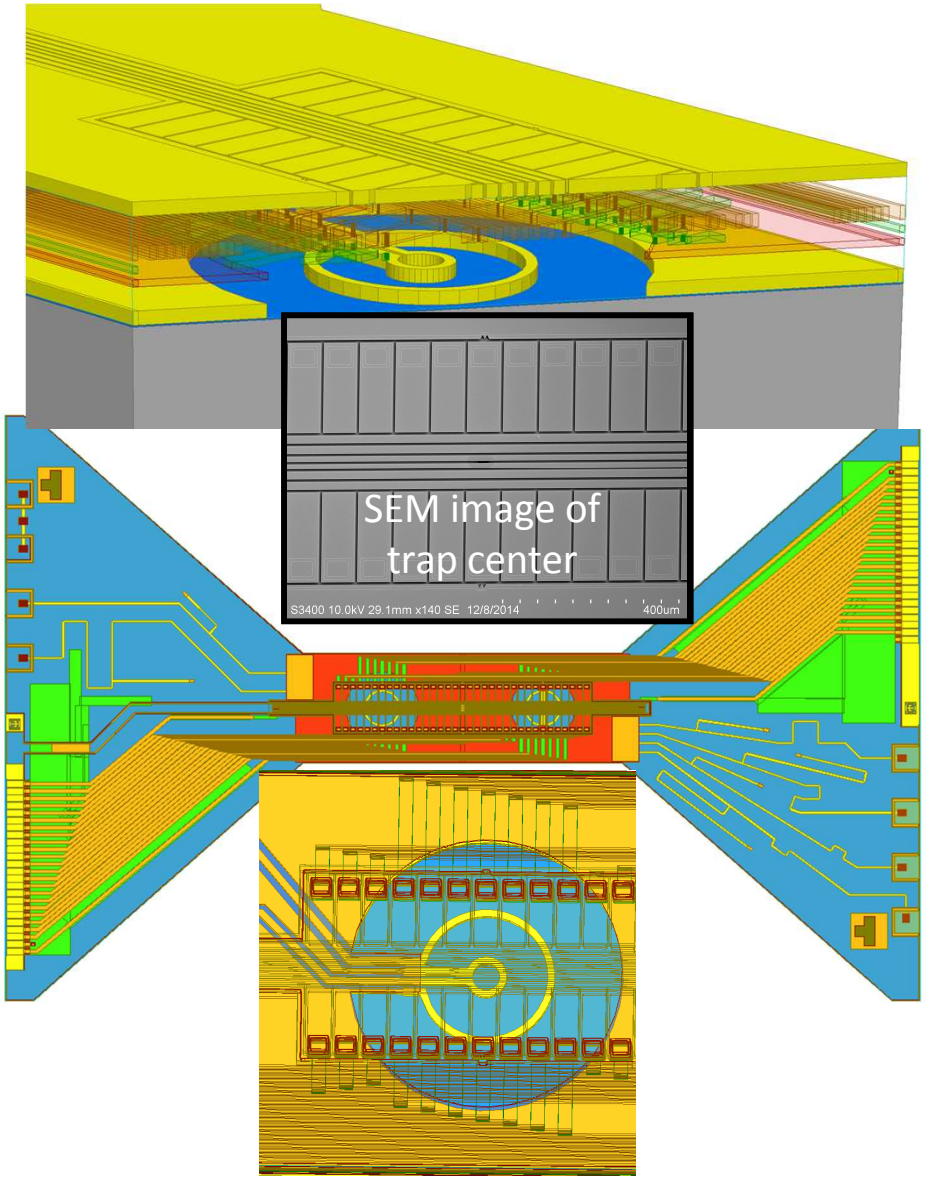
Design Guidelines
- Frequency of interest: 12.6 GHz
- Single qubit rotations: Uniform magnetic field at ion
- 2 qubit gates: magnetic field null at ion with gradient >50 T/m

Challenges (2/2015 MQCO Tech Exchange Mtg)
- High current density and thermal management
- Integrating microwave routing without sacrificing trap performance
- Impedance matching to maximize current and signal delivery

Updated Status
- Trap has been fabricated and packaged and is ready for chamber

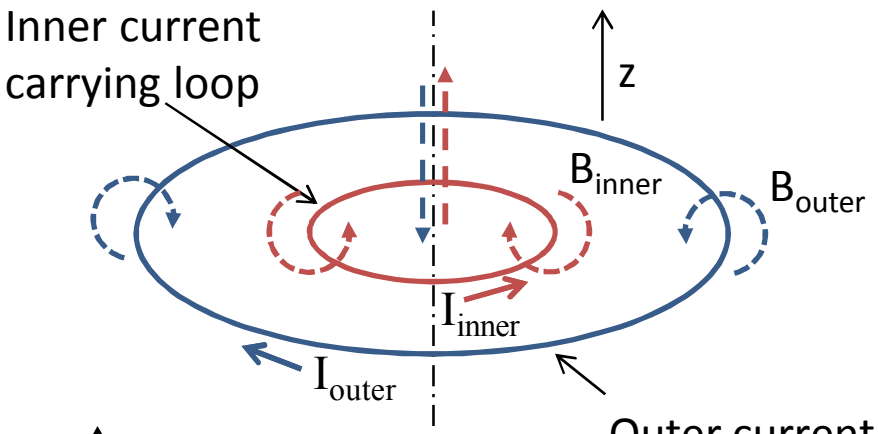
Microwave Integrated Trap *Design*

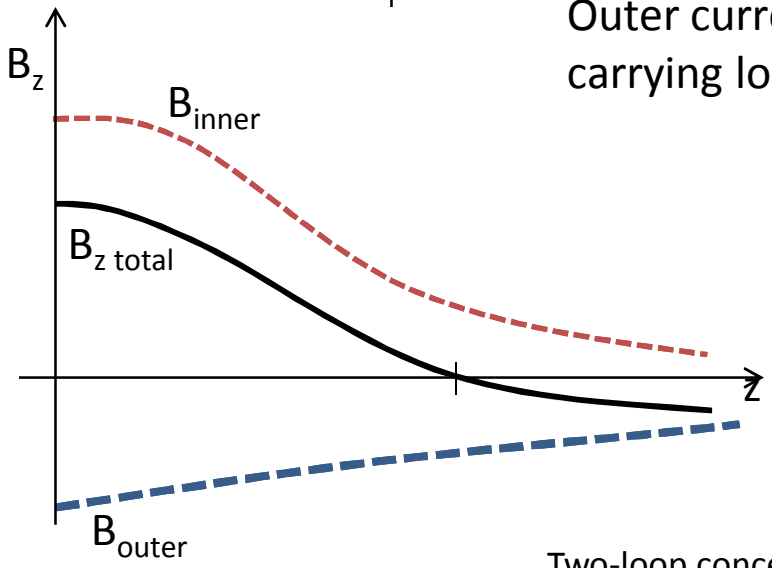
- Microwave structures integrated into the trap without disrupting the top metal
- Magnetic fields couple through slots in the metal structures, without line of sight
- Microwave traces are placed next to the substrate for heat dissipation
- On-Die Impedance matching to 50 Ω source impedance

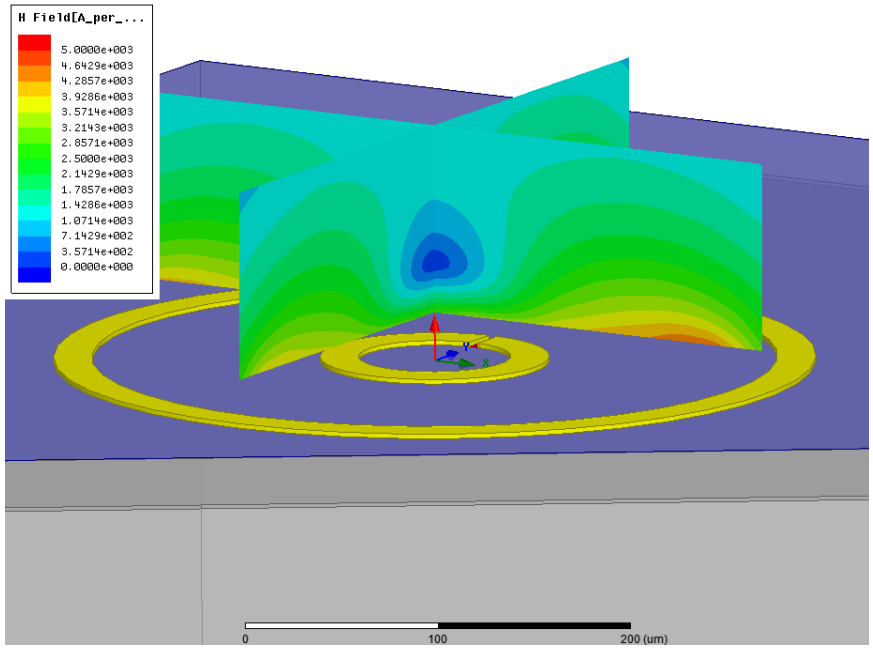


Microwave Magnetic Fields
Two-Current Loop Design

"Ideal" Two-Loop Design





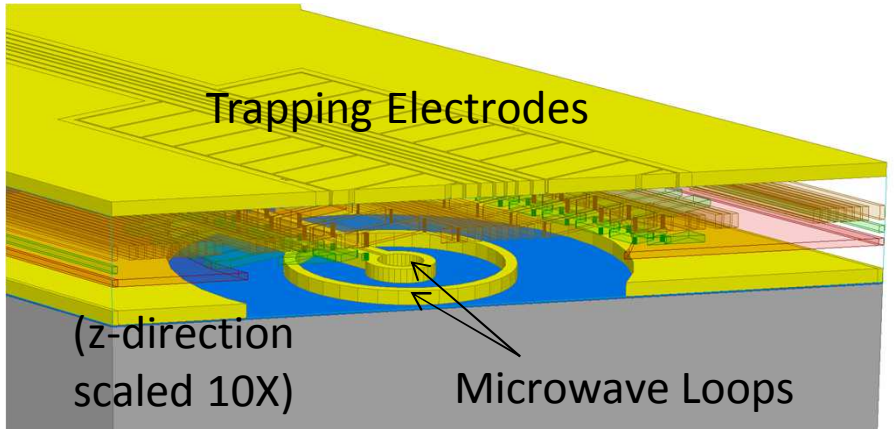


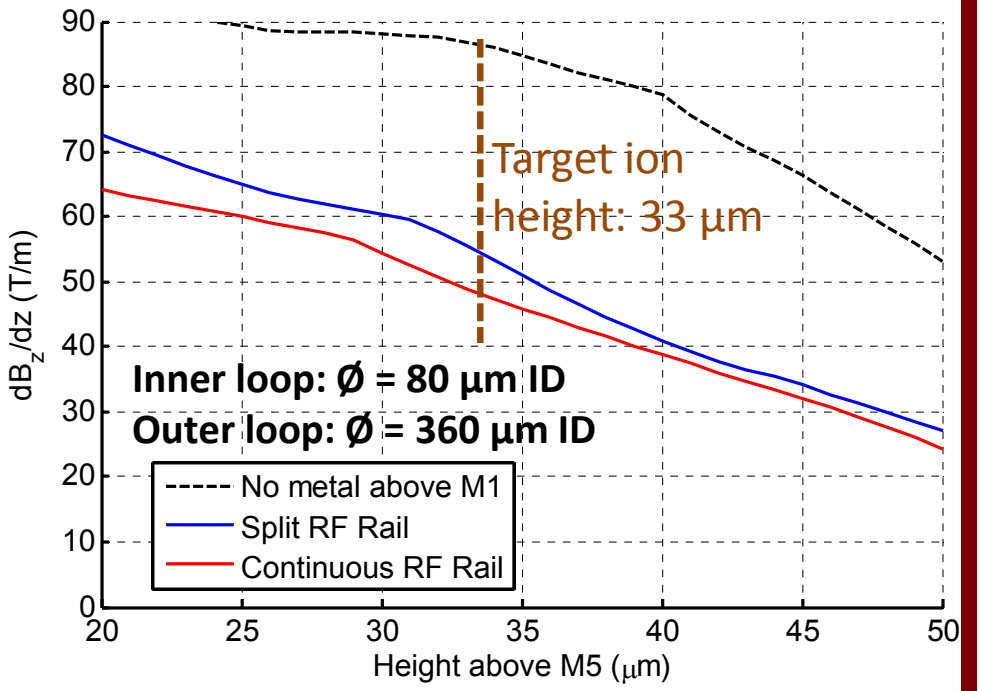
- x- and y- fields cancel along z-axis
- Generates uniform B_z and dB_z/dz with B=0
- Location of null determined by geometry and ratio of currents

Two-loop concept developed at Sandia in 2012 (SAND2015-9513)
(C. Highstrete, S. M. Scott, J. D. Sterk, C. D. Nordquist, J. E. Stevens, C. P. Tigges, M. G. Blain)

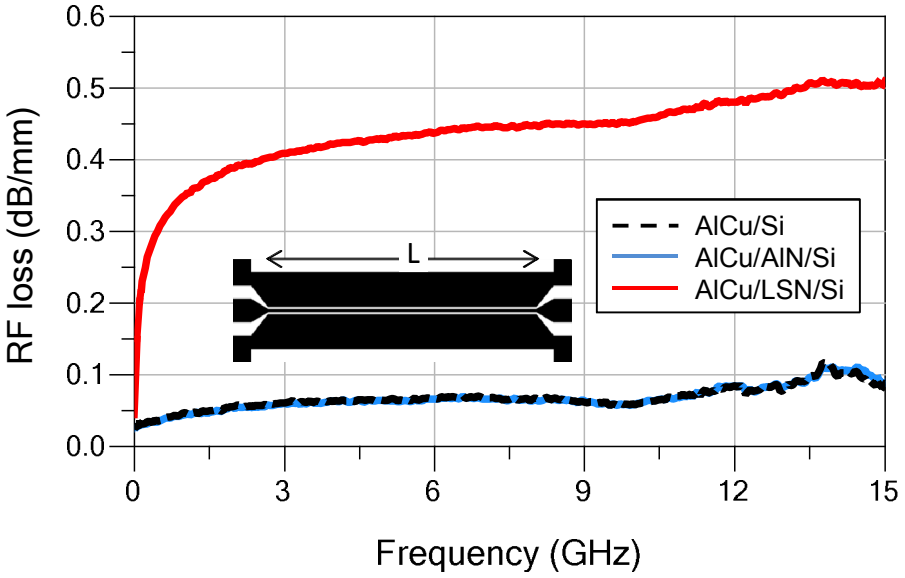
Integrating Microwave Routing *Slot-Coupled Microwaves*

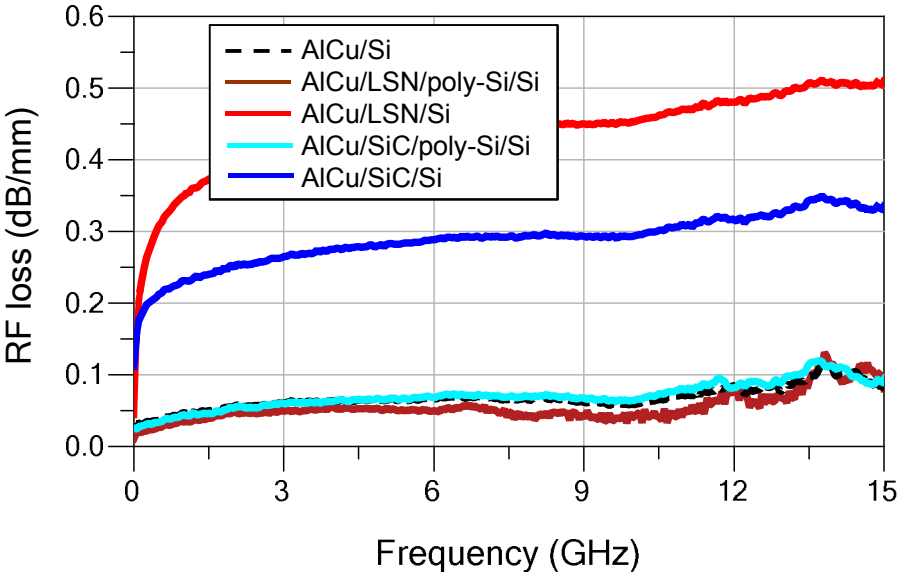
- Microwave traces have similar dimensions and locations as the control and RF electrodes: trapping region gets crowded.
- Desire to decouple the upper trapping electrodes from the microwave structures.
- Magnetic fields couple through slots in upper metal to location of ion without "line of sight".
- Approach achieves ~60% of magnetic field of bare loops





Microwave Integrated Trap
Underlying Substrate & Dielectric

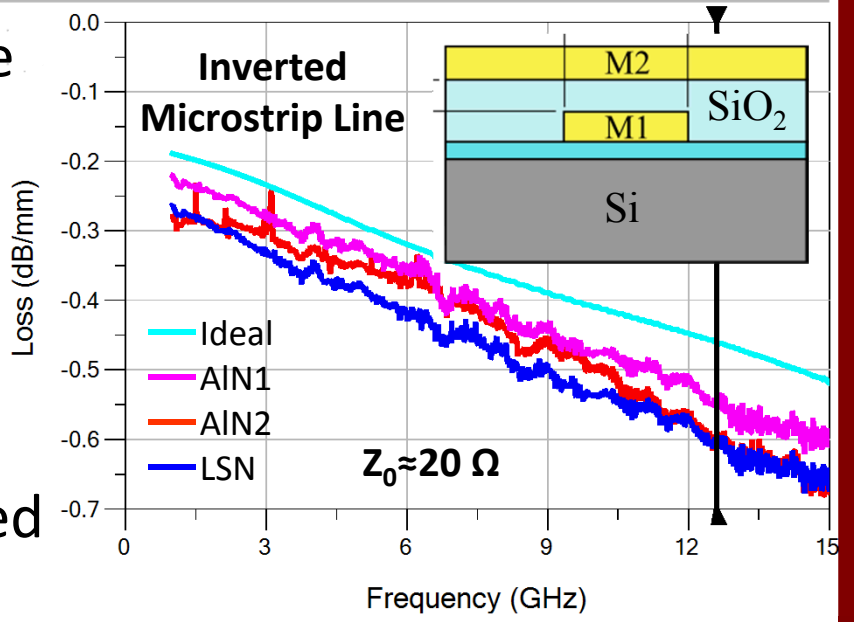


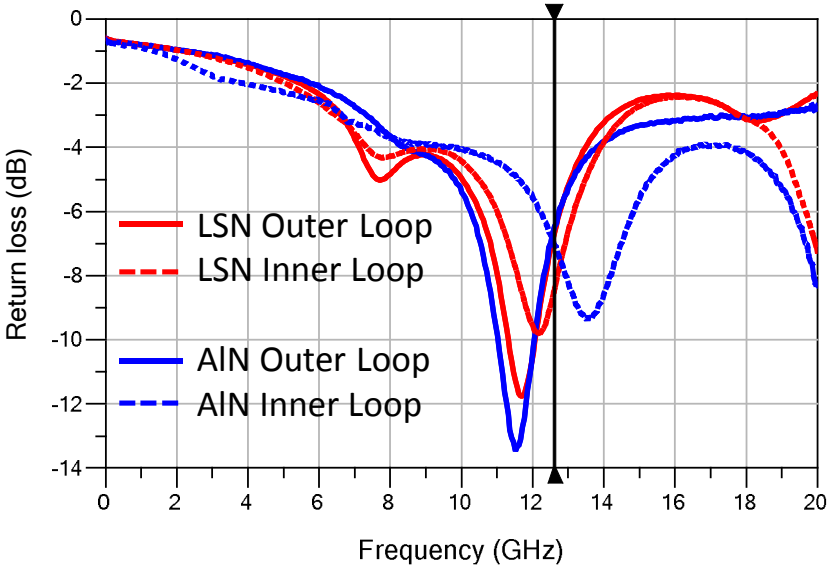


Film	CPW performance	Trap microwave performance	Thermal
AlCu/Si	Excellent	N/A (impractical due to leakage)	Excellent
AlCu/AlN/Si	Excellent	Average (suspected interface problems)	Good
AlCu/LSN/Si	Poor	Average (thickness increased)	Poor
AlCu/SiC/Si	Average	-	Excellent
AlCu/AlN/p-Si/Si	(in process)	-	Good
AlCu/SiC/p-Si/Si	Excellent	-	Excellent
AlCu/LSN/p-Si/Si	Excellent	-	Poor

Microwave Integrated Trap
Microwave Die Performance

- With thicker LSN (Si_xN_y), microwave performance is similar to AlN
- AlN wafers exhibit more loss than compared in the short loop
- Possible causes:
  - The processing steps before the deposition of AlN may have altered the interface
  - The AlN film is removed except under M1 rather than being a continuous film
- Impedance matching for both LSN and AlN wafers are within an acceptable range (>75% of power delivered to die)

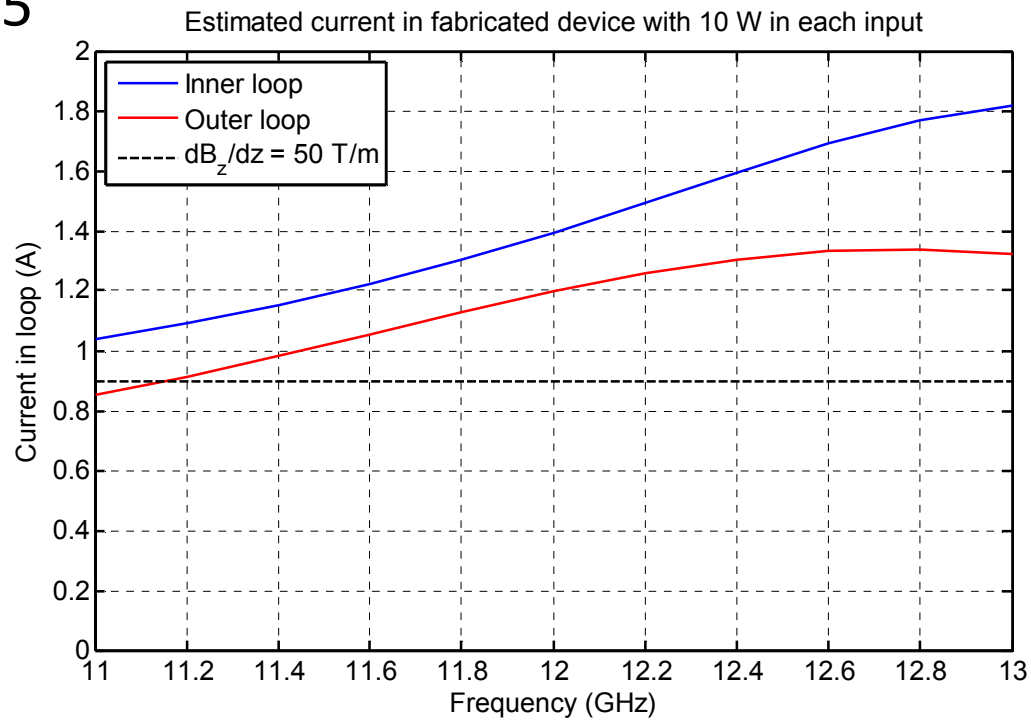




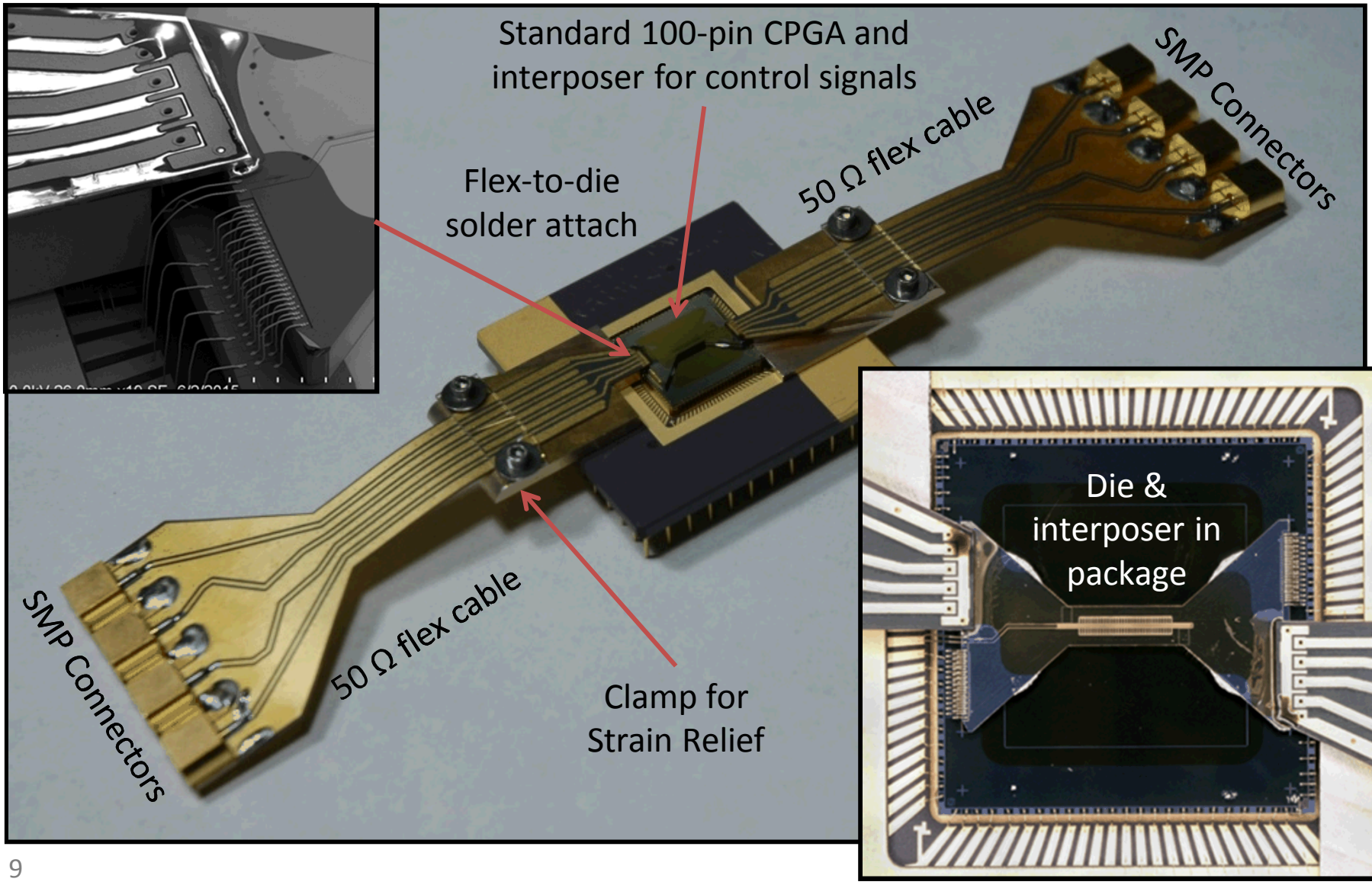
Microwave Integrated Trap
Power Handling

- Power handling capability of fabricated die investigated using microwave amplifier and high power microwave probes
- Up to 10 W Power @ 12.6 GHz introduced at contact pads without damaging device
- 10 W corresponds to $\frac{\partial B_z}{\partial z}$ ≈75 T/m (based on simulations)
- $\frac{\partial B_z}{\partial z}$ ≈50 T/m expected using
  - 4.5 W in outer loop
  - 3.0 W in inner loop

$$\frac{\partial B_z}{\partial z} \propto I \propto \sqrt{P}$$

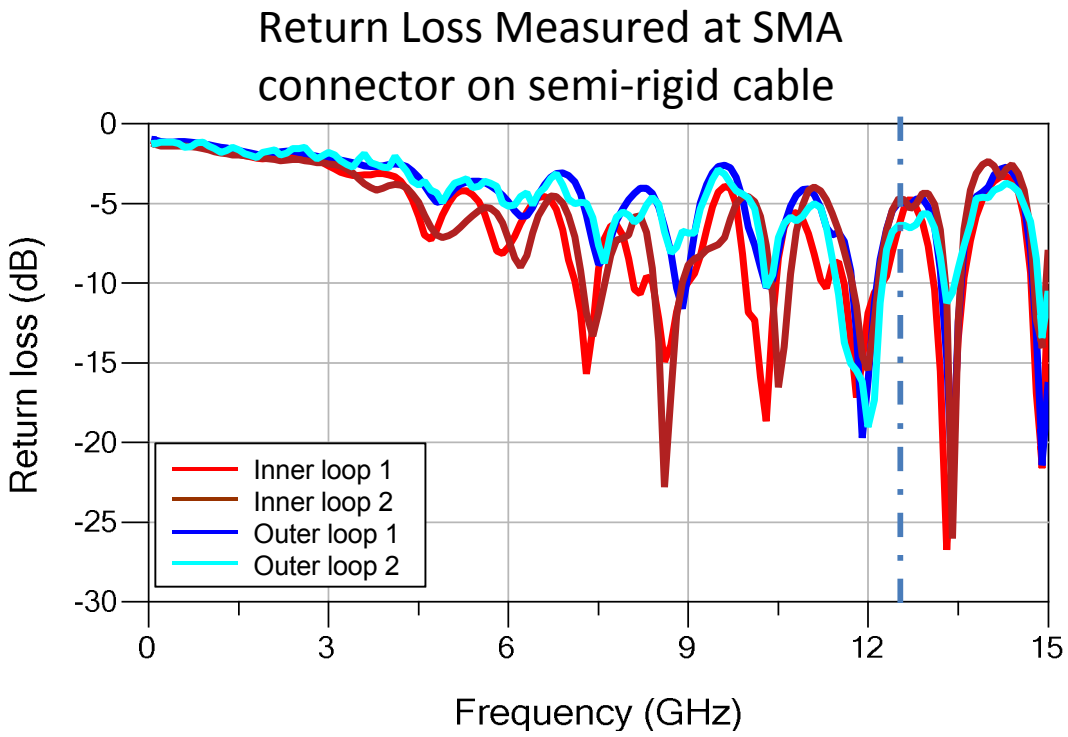


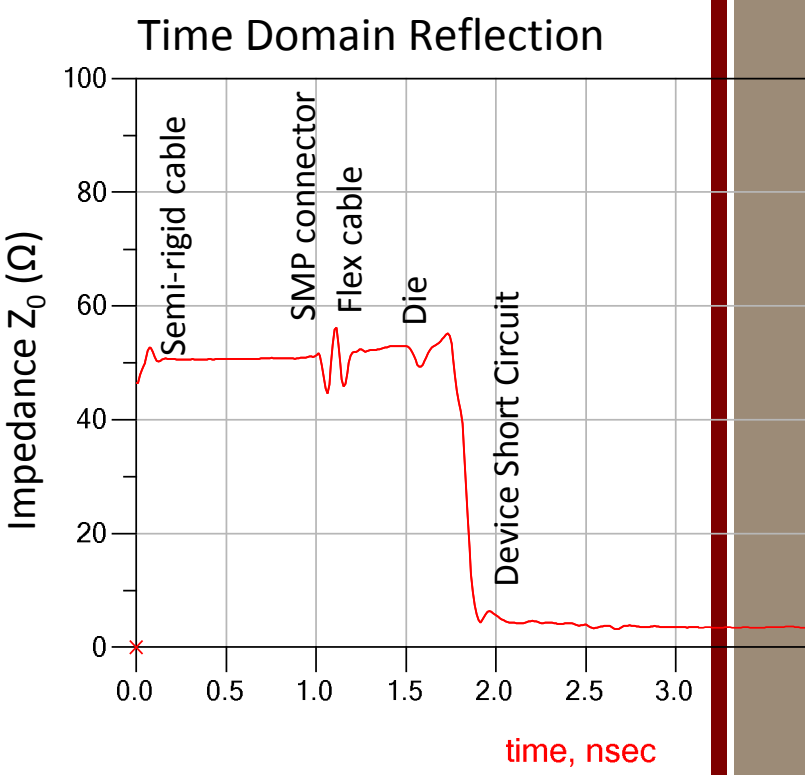
Microwave Integrated Trap
Packaging & Microwave Integration



Microwave Integrated Trap
Performance of Assembly

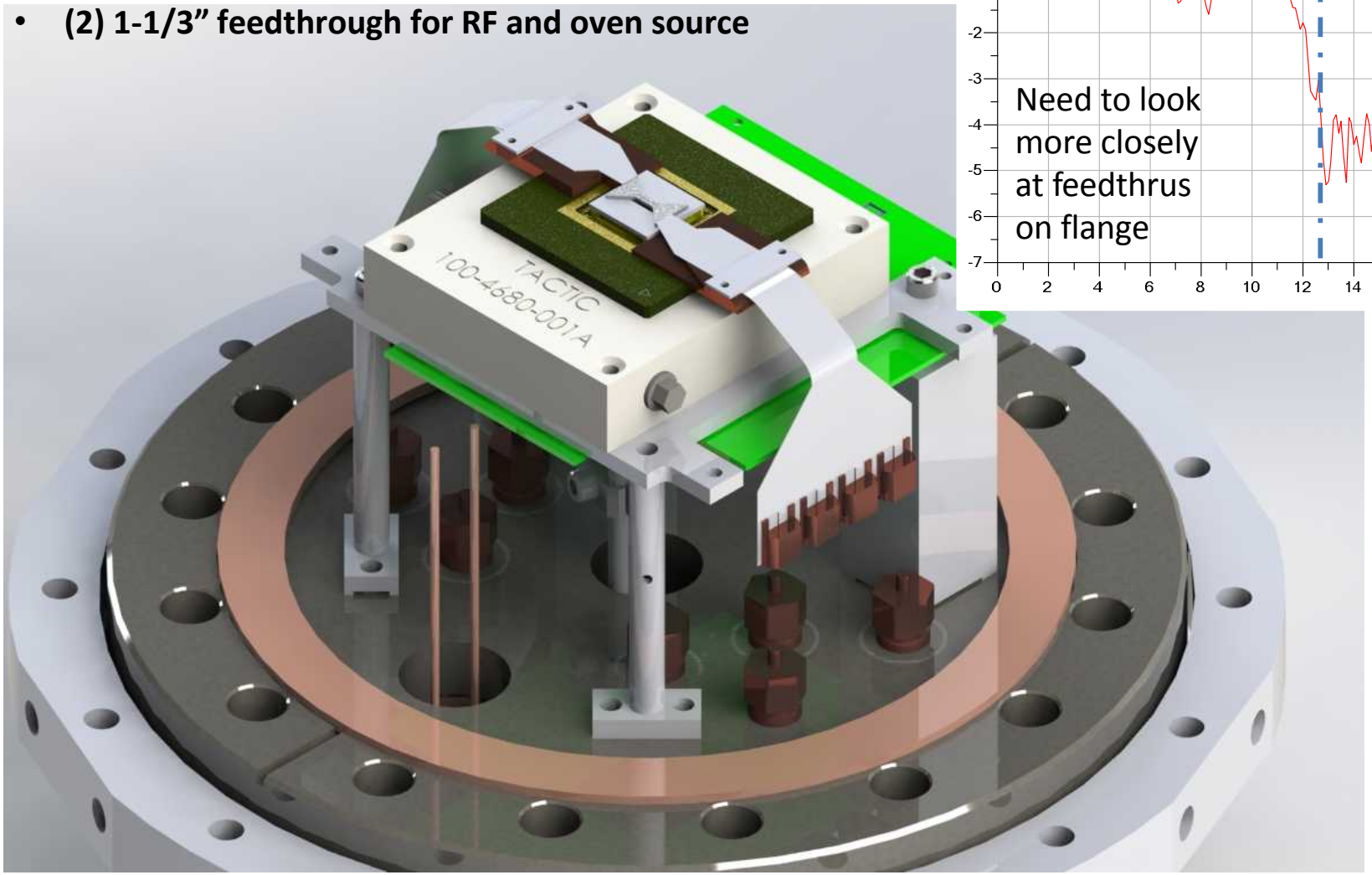
- Return Loss of assembly measured to evaluate impedance matching
- Match is Relatively Poor at 12.6 GHz but good enough for single-qubit
  - SMP / flex interface?
  - Lower frequency of on-chip match





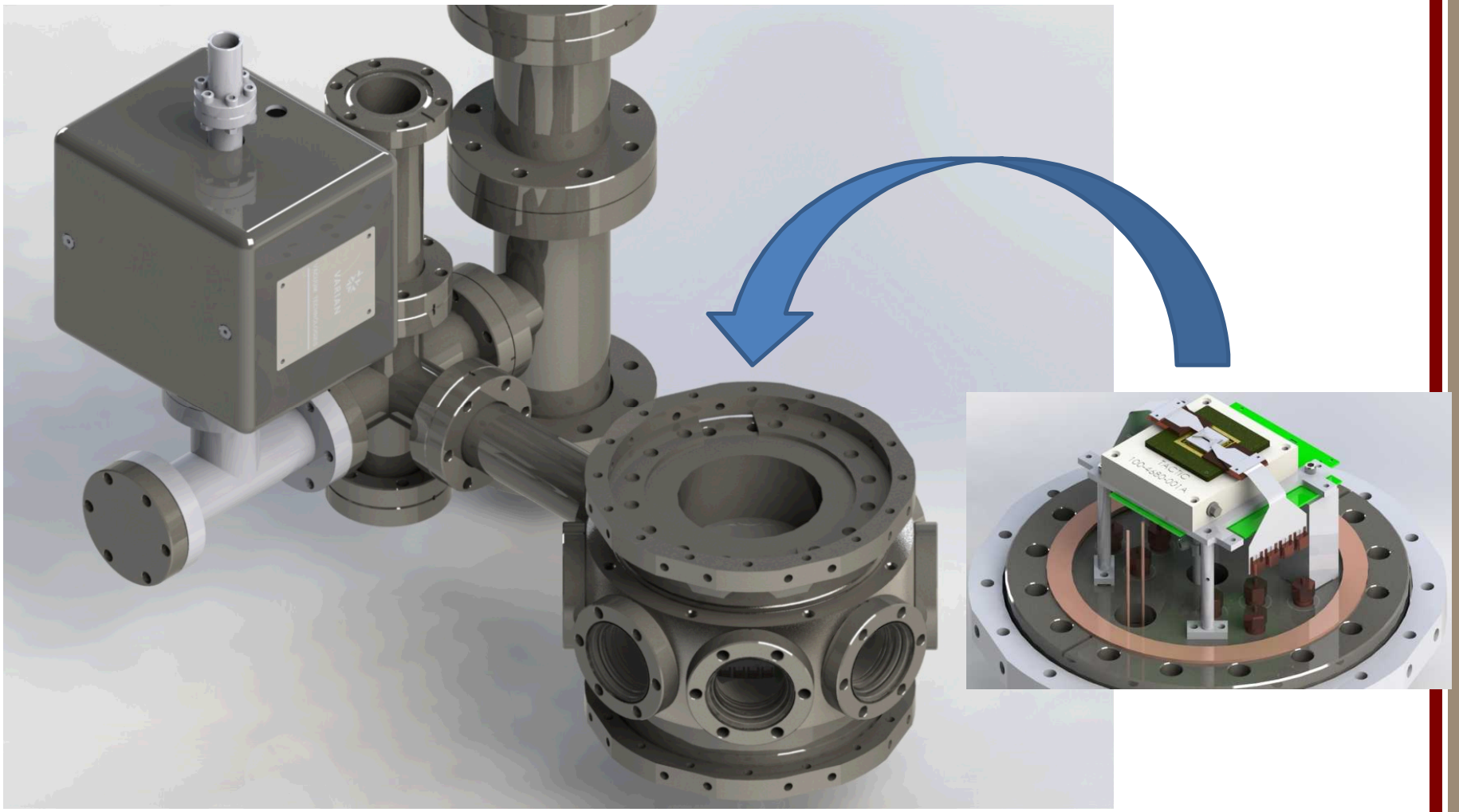
MQCO Microwave Vacuum Flange Design

- **(8) high speed SMA connectors for microwave device**
- **100 pin MDM connect**
- **(2) 1-1/3” feedthrough for RF and oven source**



Microwave chamber

Custom microwave flange will be incorporated into an existing vacuum chamber.



Microwave Integrated Trap
Summary and Next Steps

- Current Status
  - Microwave trap packaged and ready for chamber
  - Trap appears adequate for single-qubit Yb+ operation

- Issues
  - Awaiting custom microwave cables for chamber
  - Return loss of interface cabling and feedthrough
  - Delicate assembly

- Upcoming Work
  - Put into chamber & perform single-qubit (7/2015)
  - Modify trap for operation at other frequencies (summer 2015)
  - Improve microwave interface to trap (ongoing)