MINIATURE KLYSTRON FOR CUBESATS

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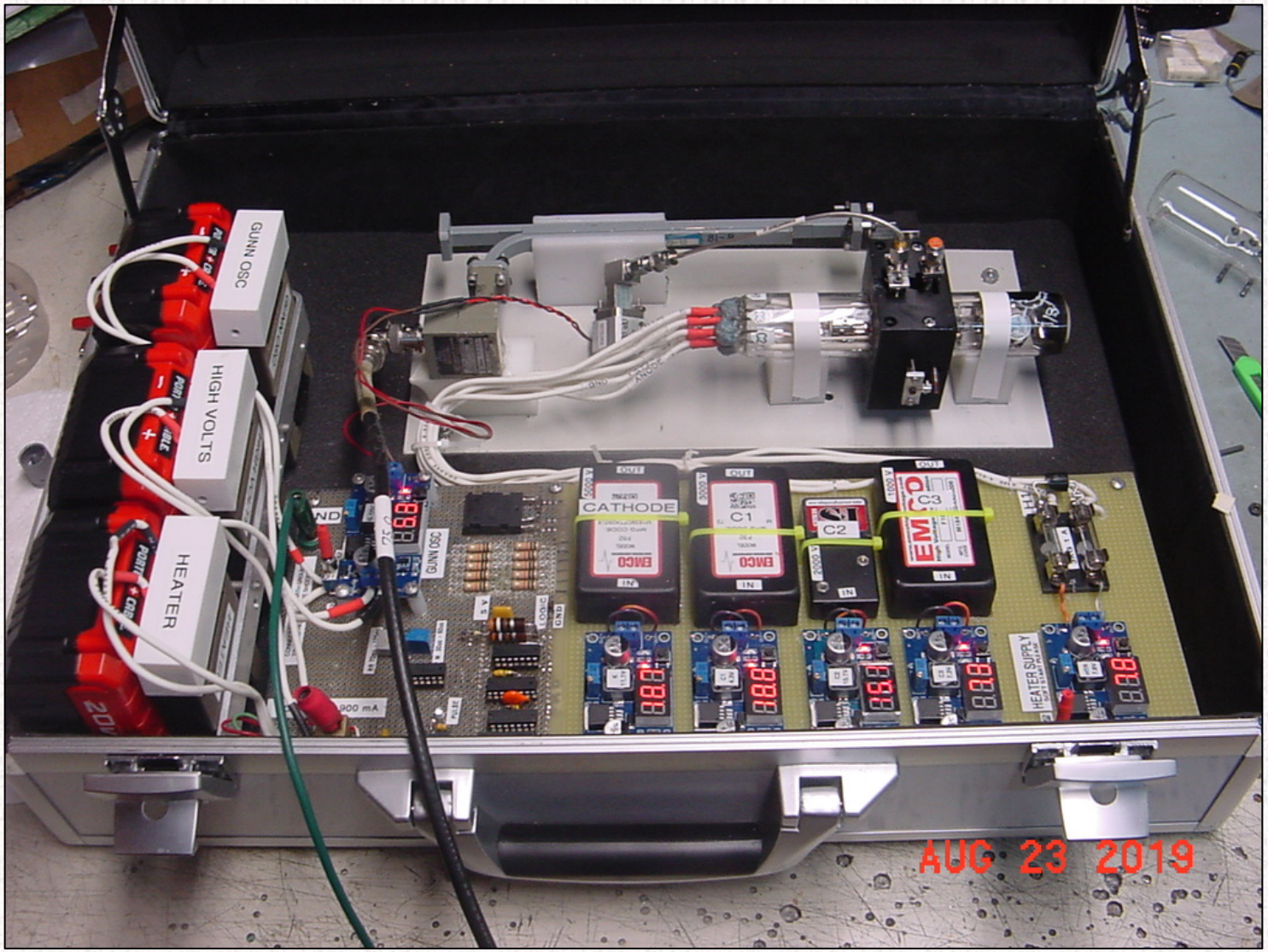
INTRODUCTION

- CubeSat technology allows inexpensive access to space.
- Constellations of CubeSats flying in formation are planned for synthetic aperture radar imaging of earth features.[1]
- CubeSats numbering in the thousands are planned for earth-wide internet service.[2]
- Both radars and broadcasting will require amplifiers at 35 GHz, having substantial output power.
- Vacuum electron devices such as klystrons and traveling wave tubes are much more efficient than solid-state power amplifiers. They are 35 times more efficient at radiating heat.

[1] A. Vance, "Pint-Size Satellites Promise Spy Quality Images Cheap," *Bloomberg Businessweek*, May 9, 2017.
[2] J. Wattles, "SpaceX launches 60 more internet satellites," *CNN Business*, Nov. 11, 2019.

DEMO UNIT: TUBE AND ELECTRONICS, RF SOURCE, LOAD, AND DIAGNOSTICS



DEVICE FEATURES

- 3 klystrons constructed and tested
- Four cavities
- Novel construction technology
- Beam tunnel 0.020 inch, beam diameter 0.014 inch
- Four-stage graphite depressed collector
- Nano-doped scandate cathode 1.2 mm diameter, 0.6 watt dissipation
- Glass envelope allowing efficient radiation of heat to space
- Floating anode
- Periodic permanent magnet focusing inside envelope
- Novel cavity tuning
- Novel input and output coupler design
- 4.0 kV, 30 mA, 120 watts in beam
- Only 8 cm long x 2.8 cm diameter
- Weight: Less than 1 lb.

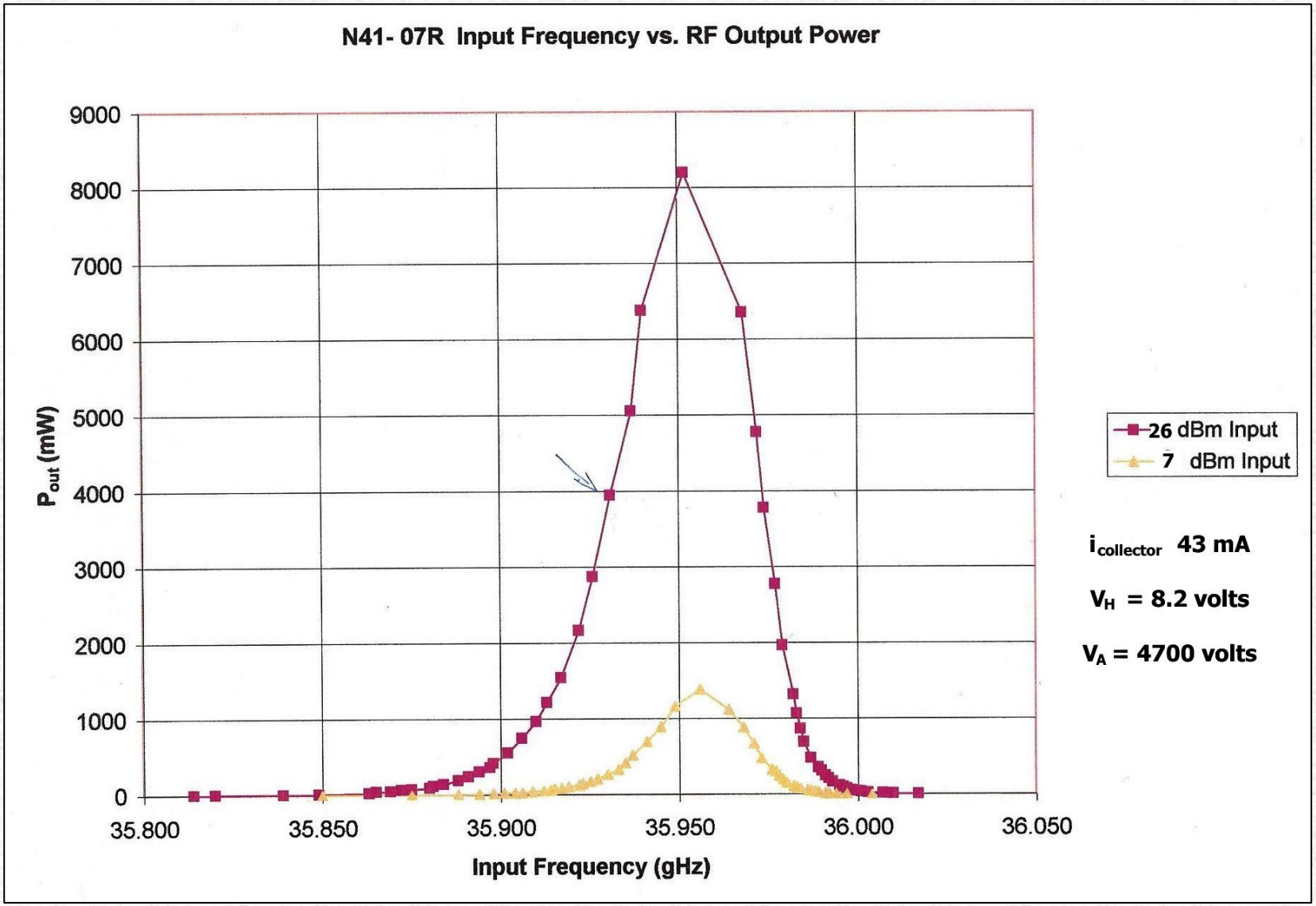
PERFORMANCE GOALS

- Volume < 1U (10 cm x 10 cm x 10 cm)
- Sat output – 32 watts
- Duty factor – 12%
- Large signal gain – 35 dB
- Frequency – 35.7 GHz
- Bandwidth – 60 MHz
- Efficiency – 50%

<u>Actual Best Values</u>

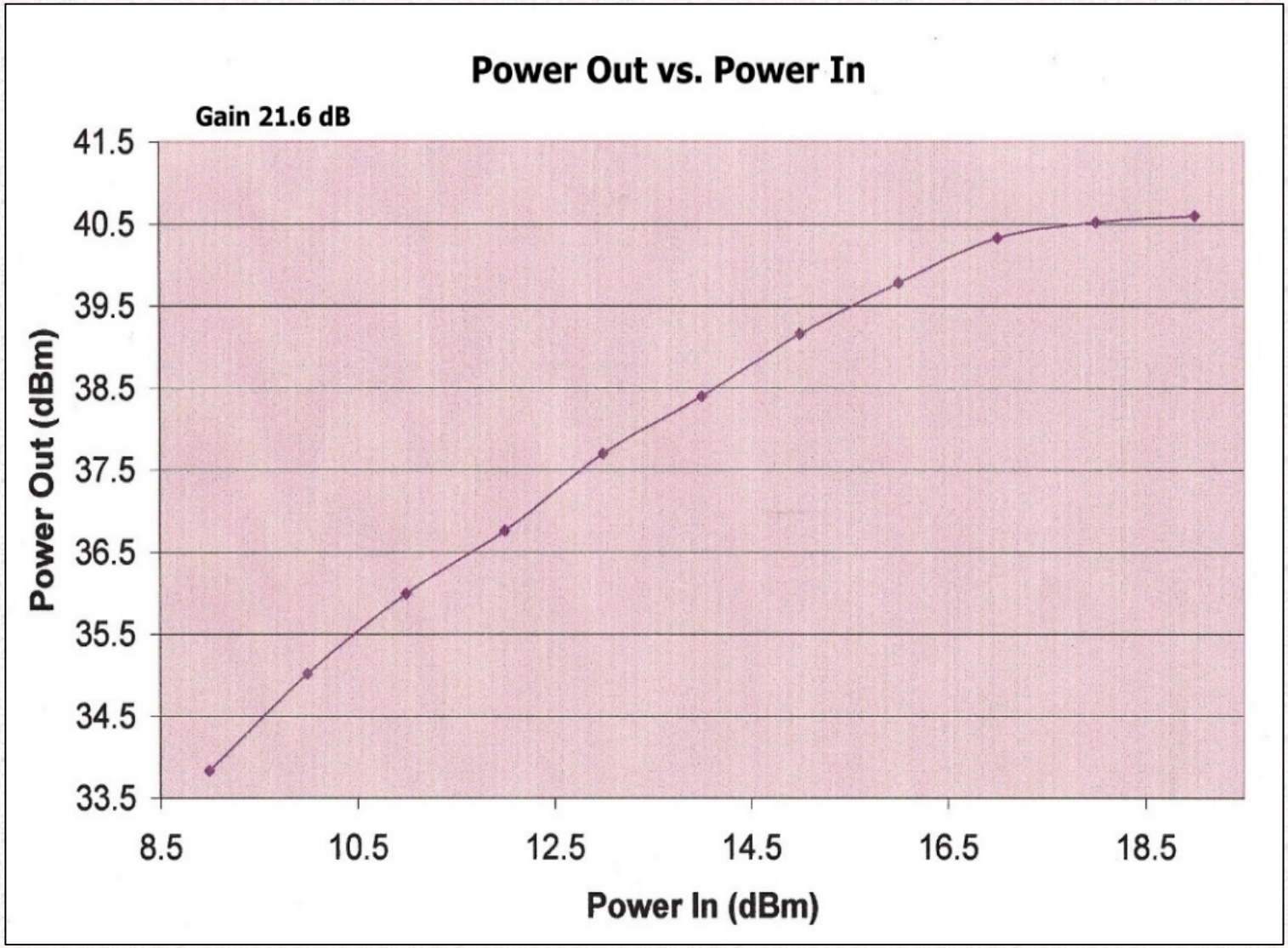
- Power out – 22 watts
- Gain – 27 dB
- Bandwidth – 40 MHz
- Efficiency - ~38%

MEASURED BANDWIDTH



GAIN VERSUS POWER IN

N4107



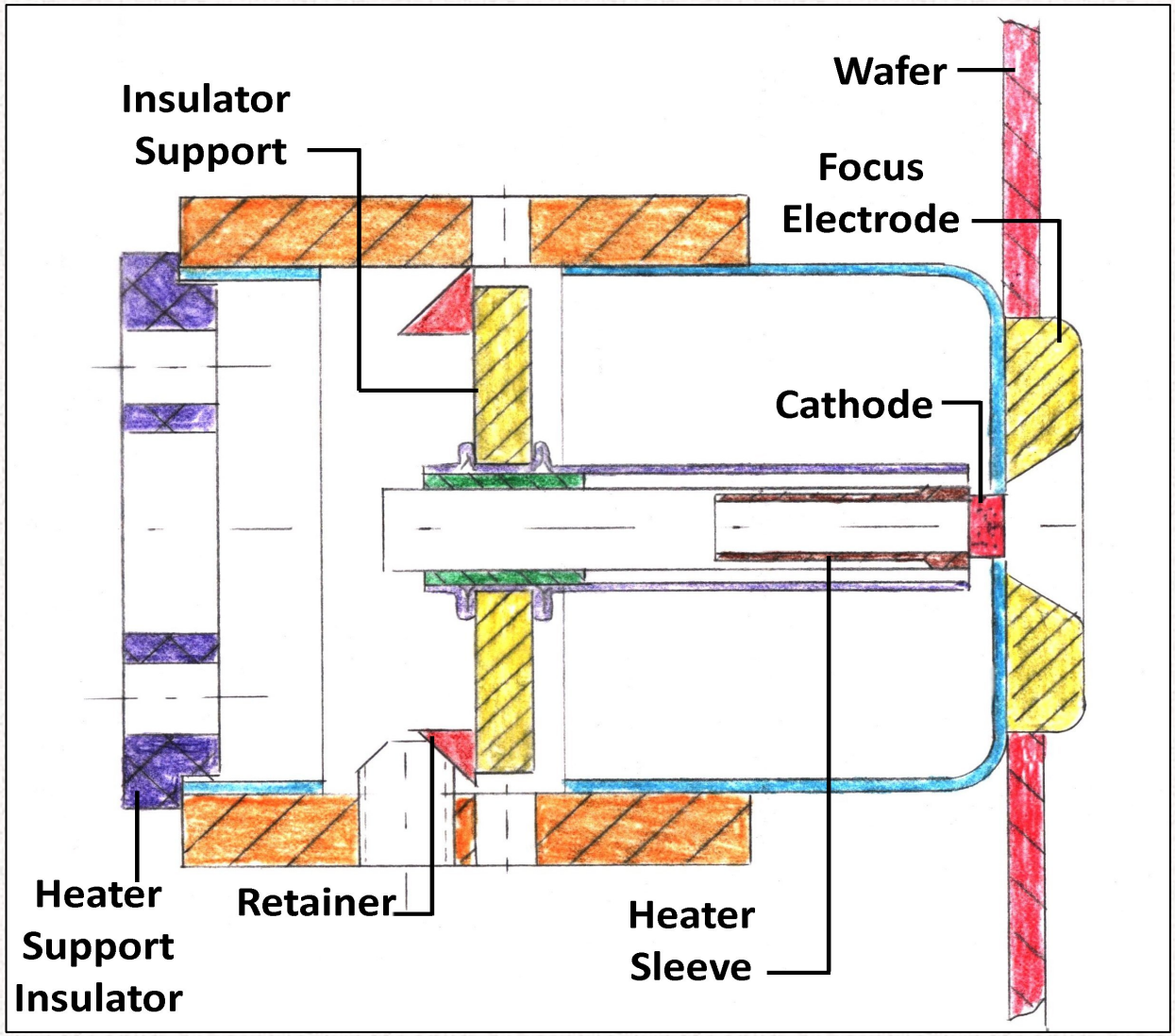
KEY ELEMENTS OF CONSTRUCTION TECHNOLOGY

- Glass envelope allows radiation cooling.
- Electron gun, RF/focusing stack, and collectors integrated into a single module.
- Wiring and magnets inside the vacuum envelope.
- Cavities and magnets held in place by mechanical capture.
- Molten glass rod supports provide alignment and spacing to within 0.013 mm.
- 4-stage depressed collector is greatly simplified.

ELECTRON GUN FEATURES

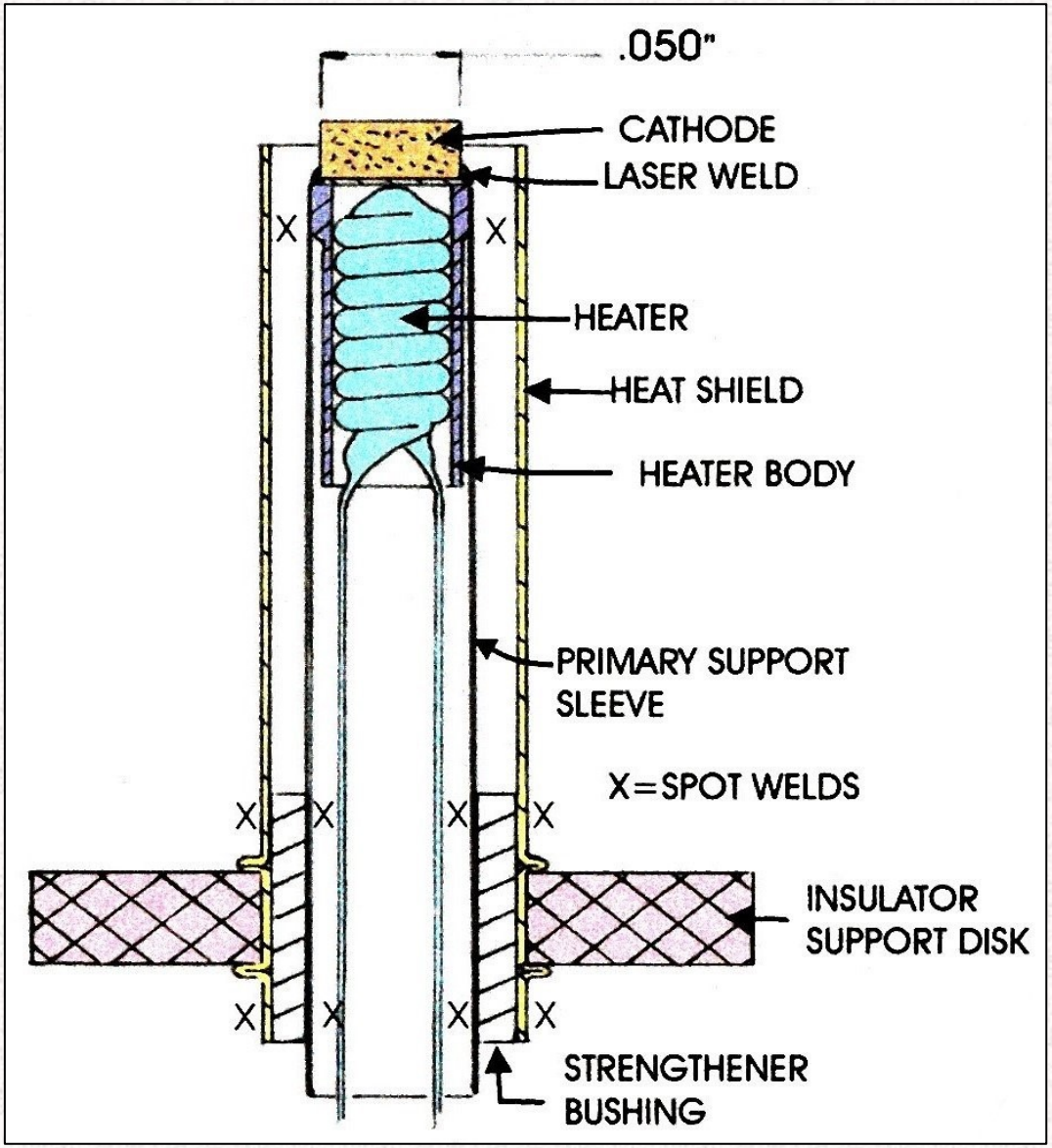
- Focus electrode is a simple demountable construction utilizing spot welds and mechanical capture.
- Snouted floating anode made of magnetic material to block B field to cathode (gun employs Brillouin flow).
- Cathode mount maximizes mechanical stability and thermal isolation.
- A miniature highly loaded nanoscandia-doped tungsten cathode.

FOCUS ELECTRODE DESIGN



FLOATING SNOUTED ANODE IN WAFER

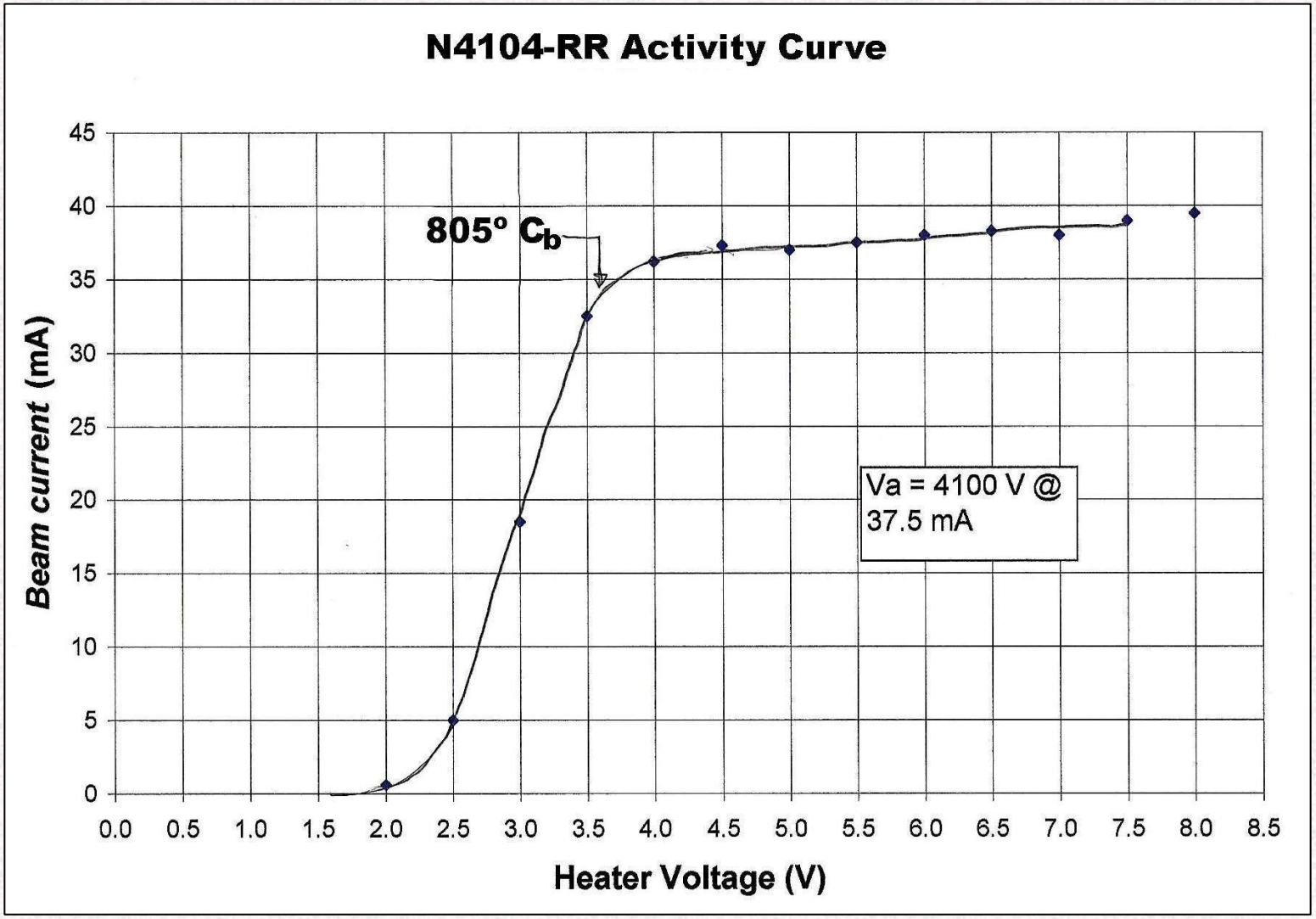
0.050-INCH CATHODE ASSEMBLY



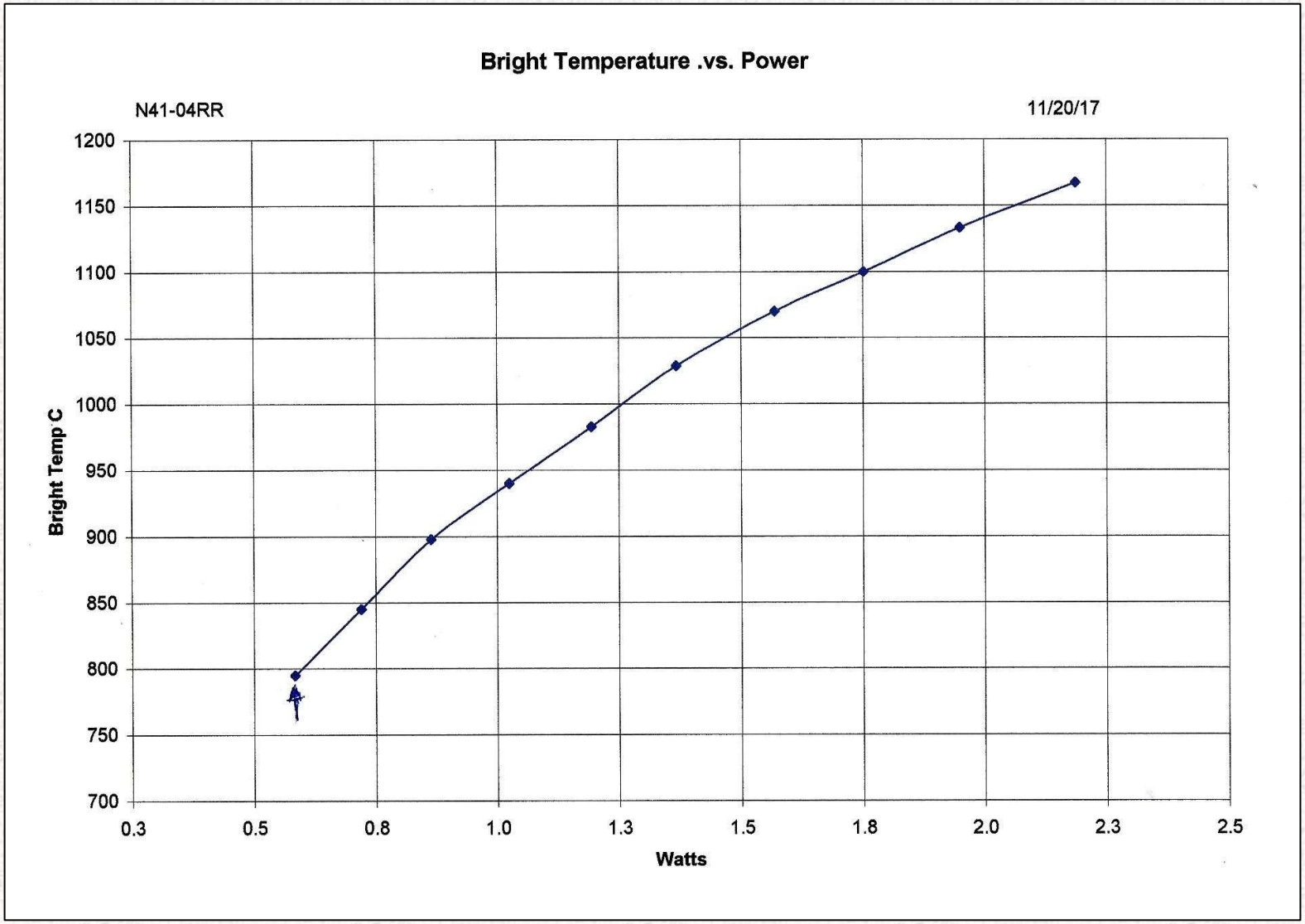
CATHODE ASSEMBLY

PLANAR SCANDATE CATHODE ON HEATER ENCLOSURE

SCANDATE CATHODE ACTIVITY CURVE



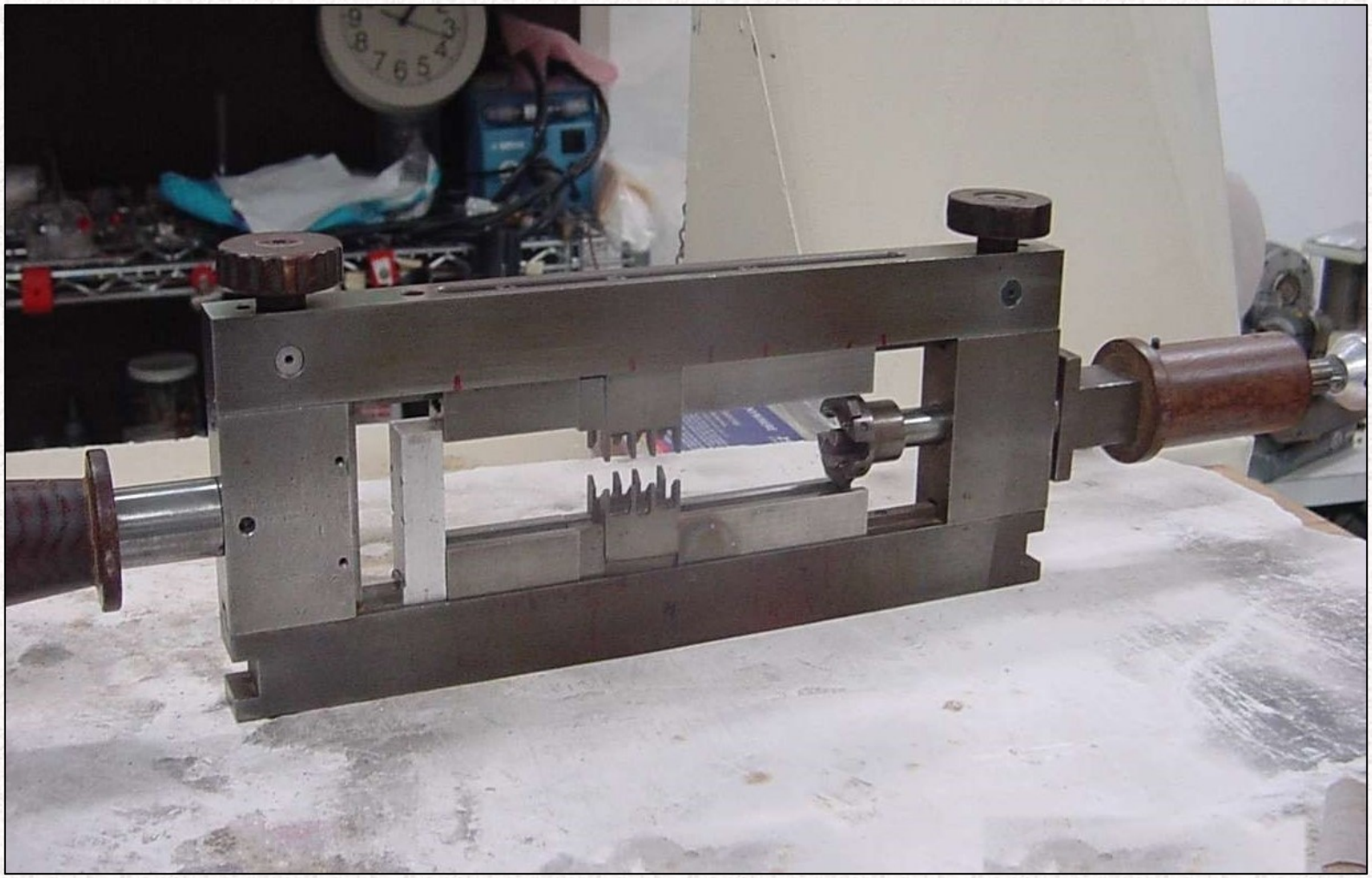
BRIGHT TEMPERATURE VS. POWER



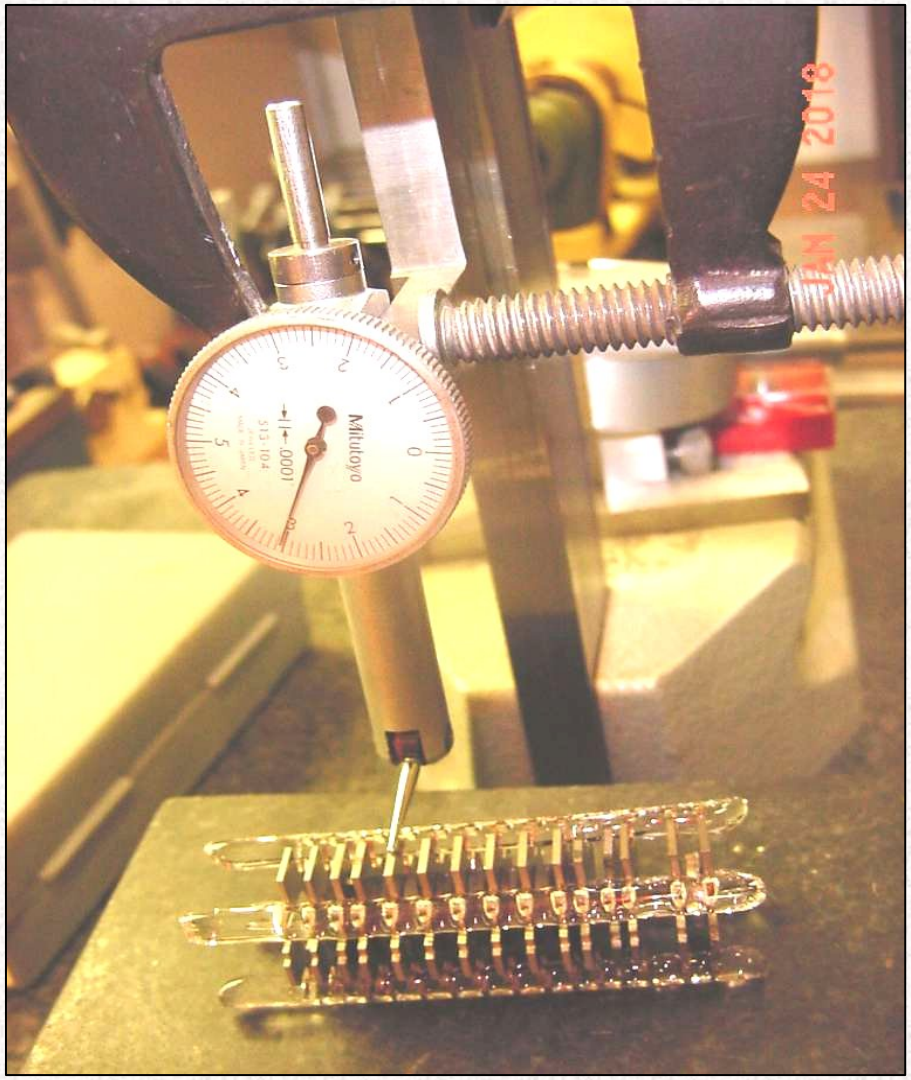
GLASS-RODDED STRUCTURE

- Parts are aligned and spaced on a precision rodding jig.
- The assembly, including focus electrode, anode, RF/magnet stack, and collector wafers, is then fastened and insulated via molten Pyrex rods.
- The rodded assembly is mounted on a glass feedthrough stem, which is flame-sealed into a glass envelope.

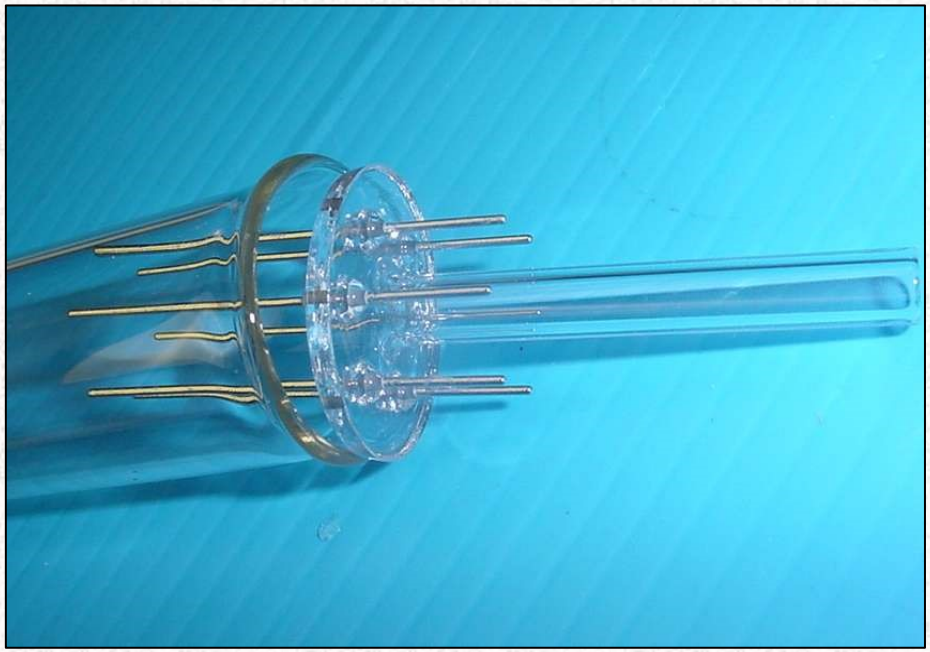
RODDING JIG



RODDED ASSEMBLY UNDERGOING INSPECTION



GLASS ENVELOPE AND STEM



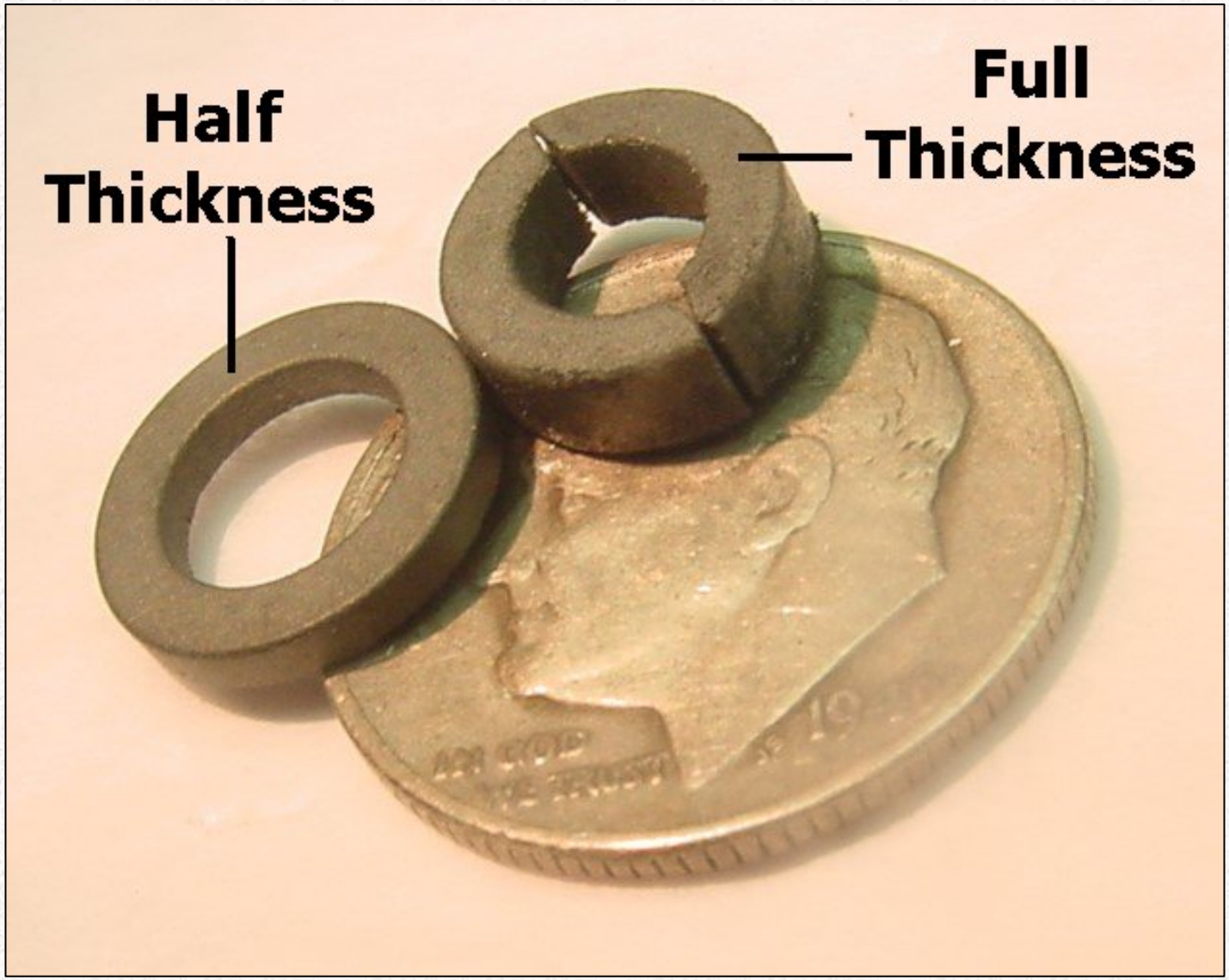
Unsealed

Sealed

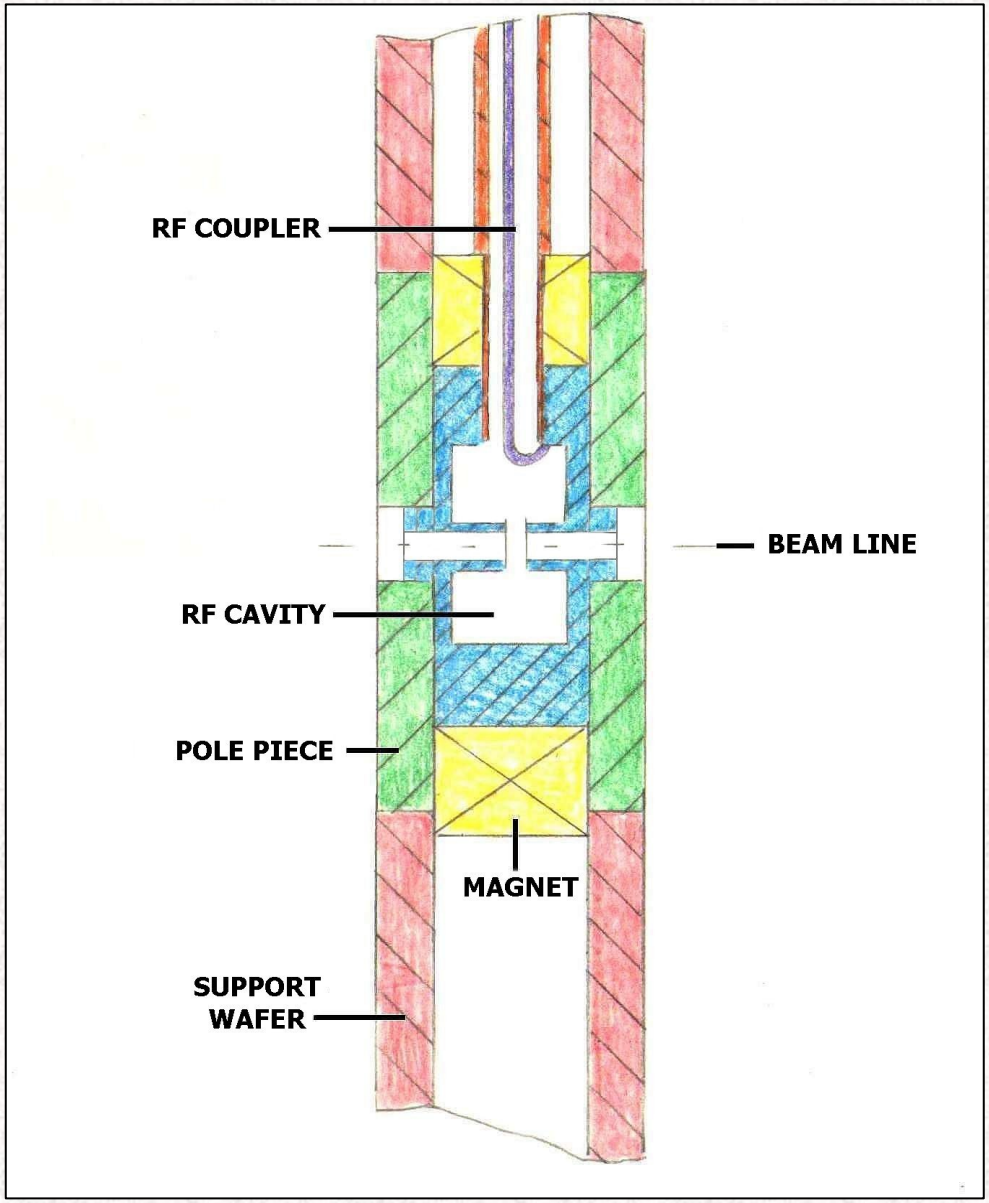
MAGNET STACK FEATURES

- Device used very small, off-the-shelf samarium-cobalt ring magnets held by mechanical capture.
- Magnetic field reduced and profiled by precision heating.
- Half-thickness magnets used at the ends.
- Magnets inside vacuum envelope, which means they were baked at 400º C.
- Magnets slightly outside the pole pieces.
- Magnetic field at the cathode was only 0.5 Gauss from over 2000 Gauss along the beam axis.
- Focusing adjustable via small button magnets glued to outside of vacuum envelope.

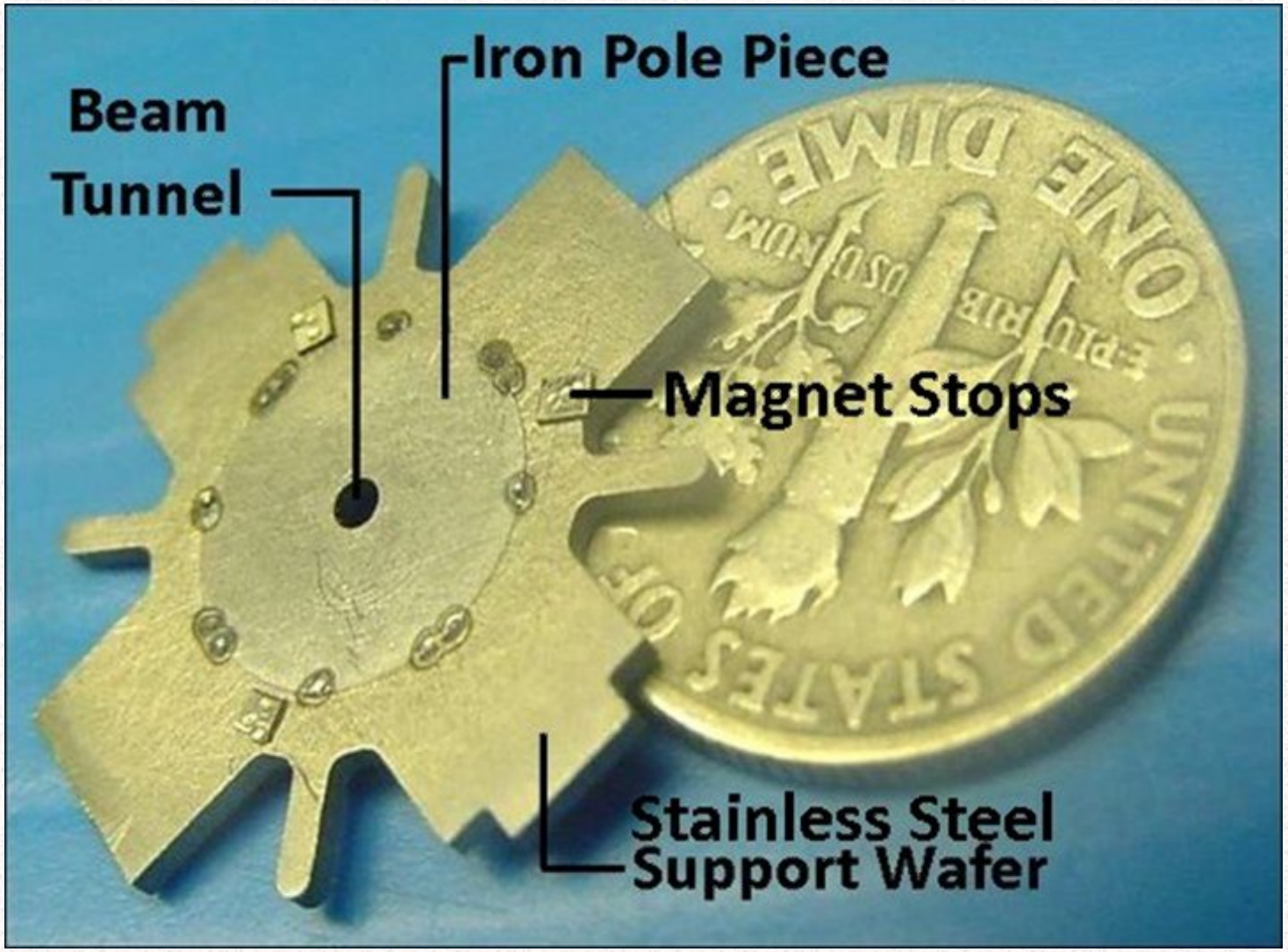
SAMARIUM COBALT MAGNETS



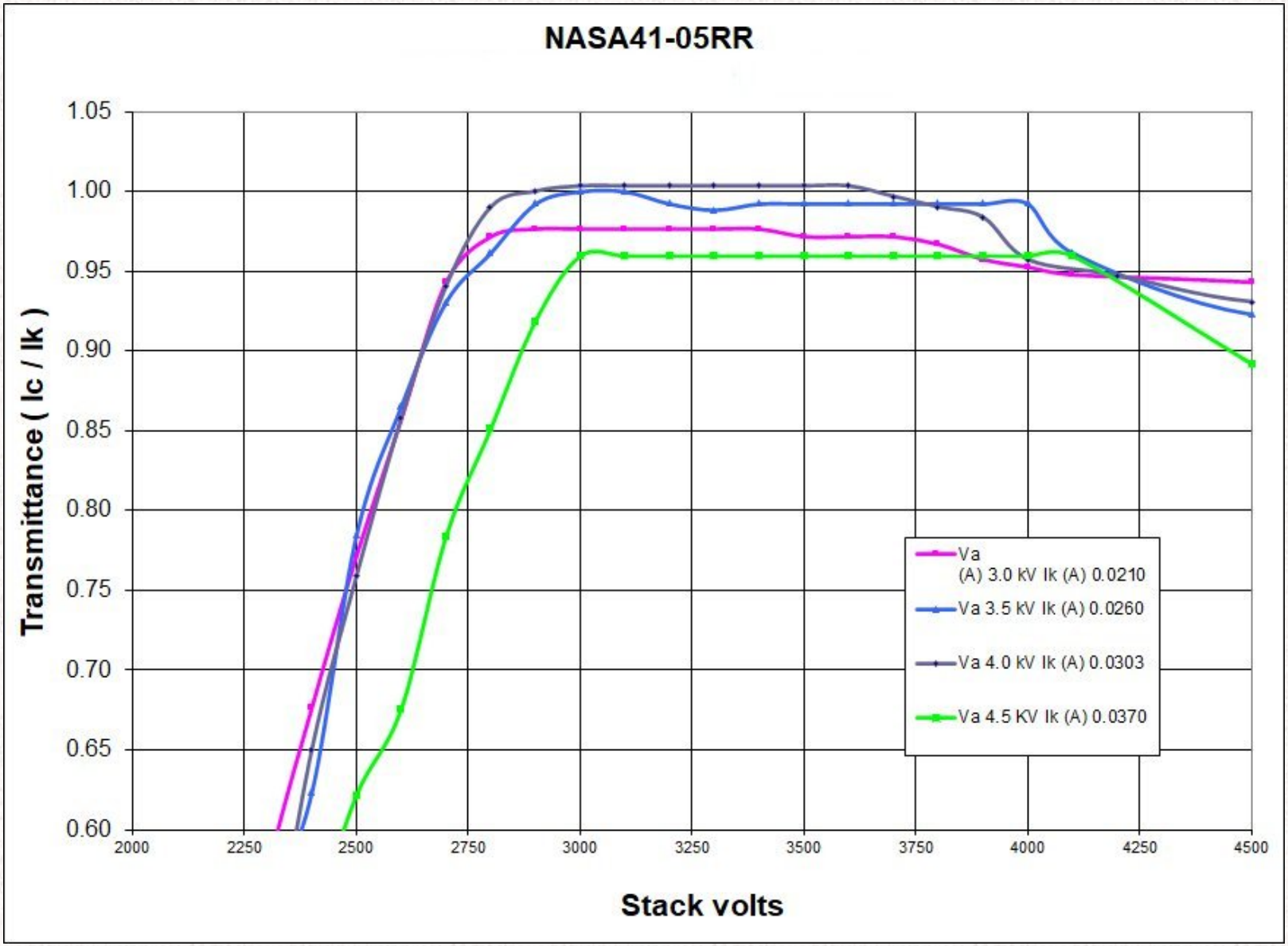
CAVITY/FOCUSING STRUCTURE



POLE PIECE WELDED INTO WAFER



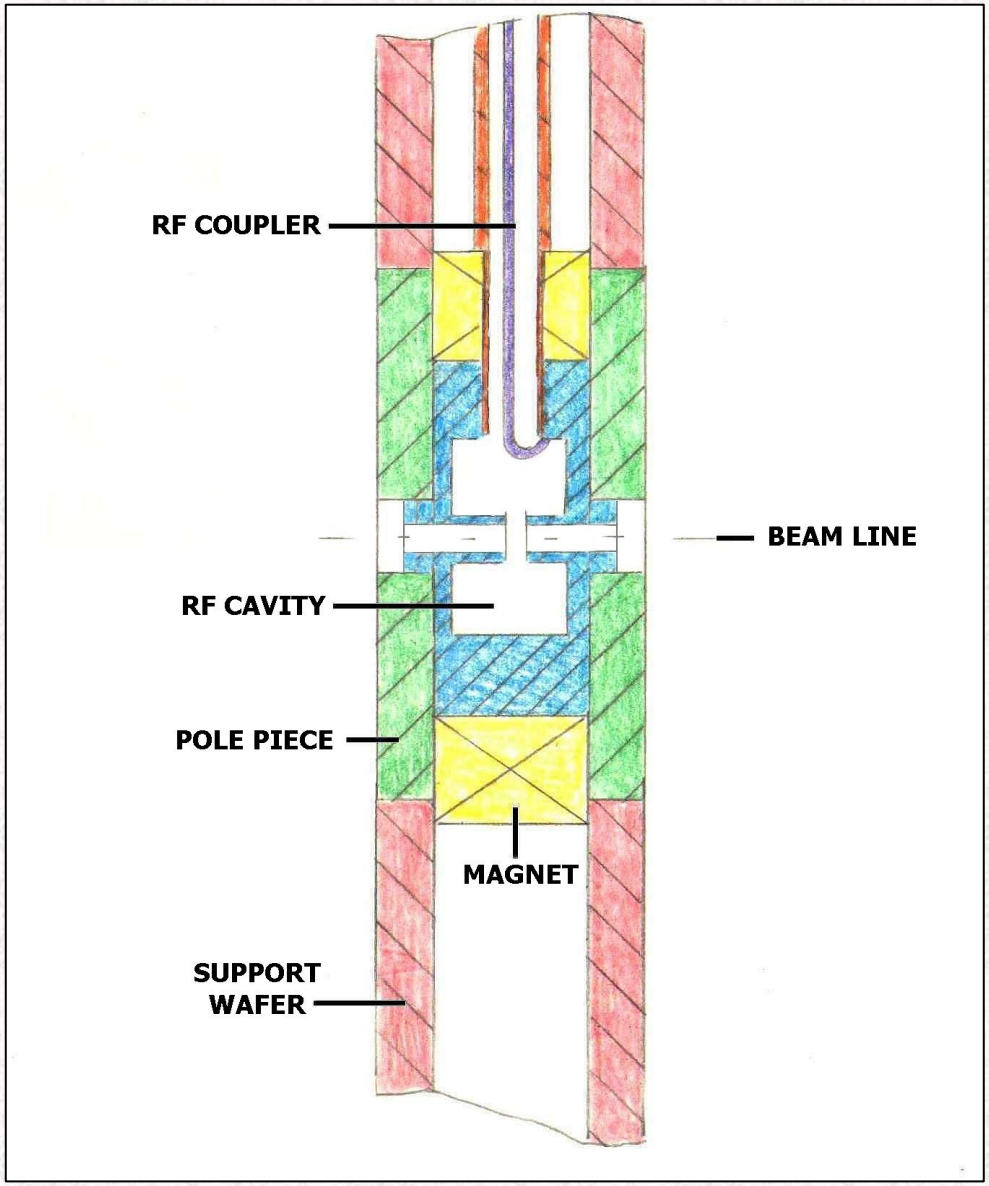
TRANSMITTANCE VS. STACK VOLTS



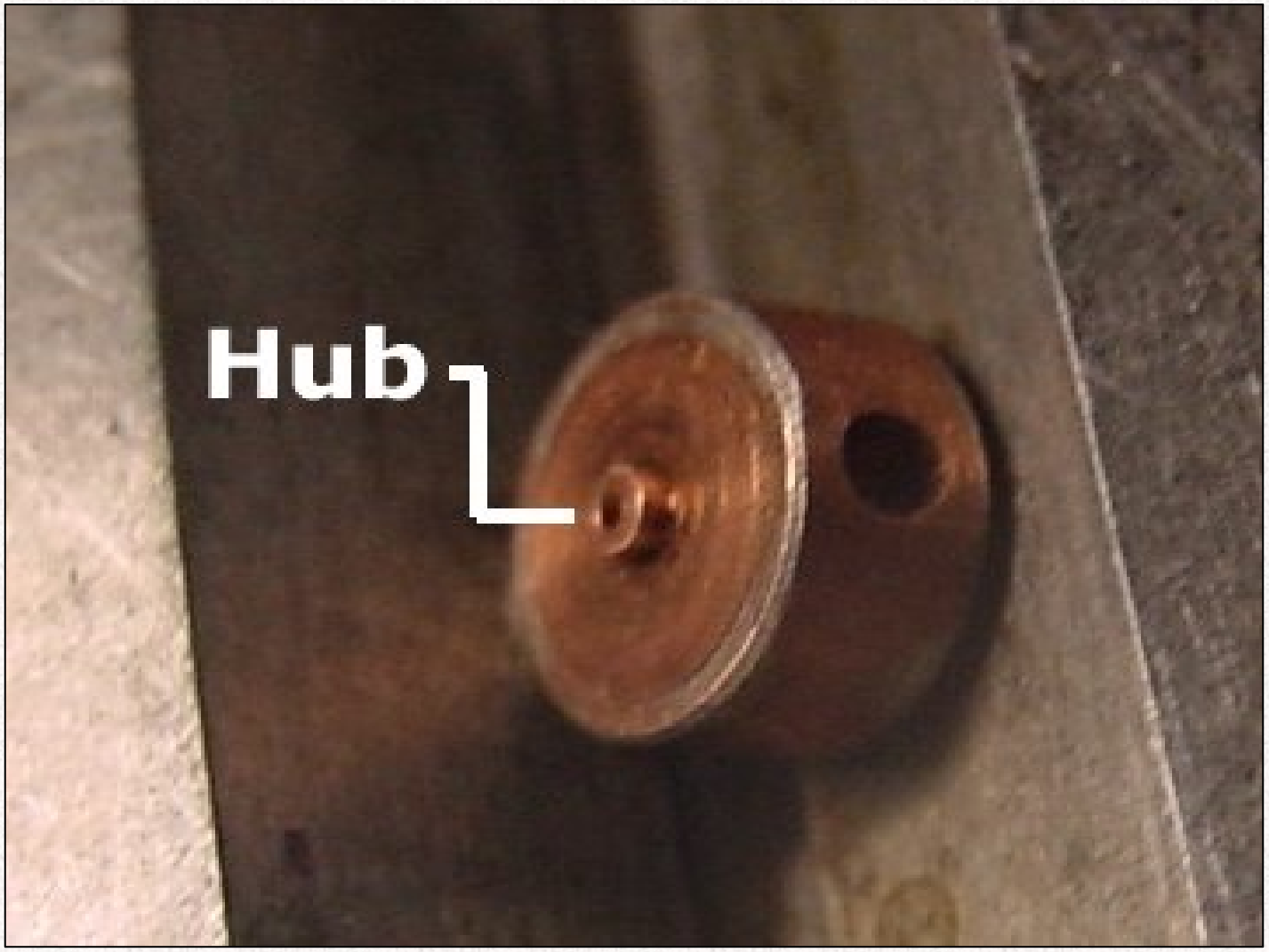
RF CAVITIES

- Held by mechanical capture.
- Three pieces OFHC copper, hand-machined by e beam and brazed together.
- Ferrule gap completely adjustable after brazing.

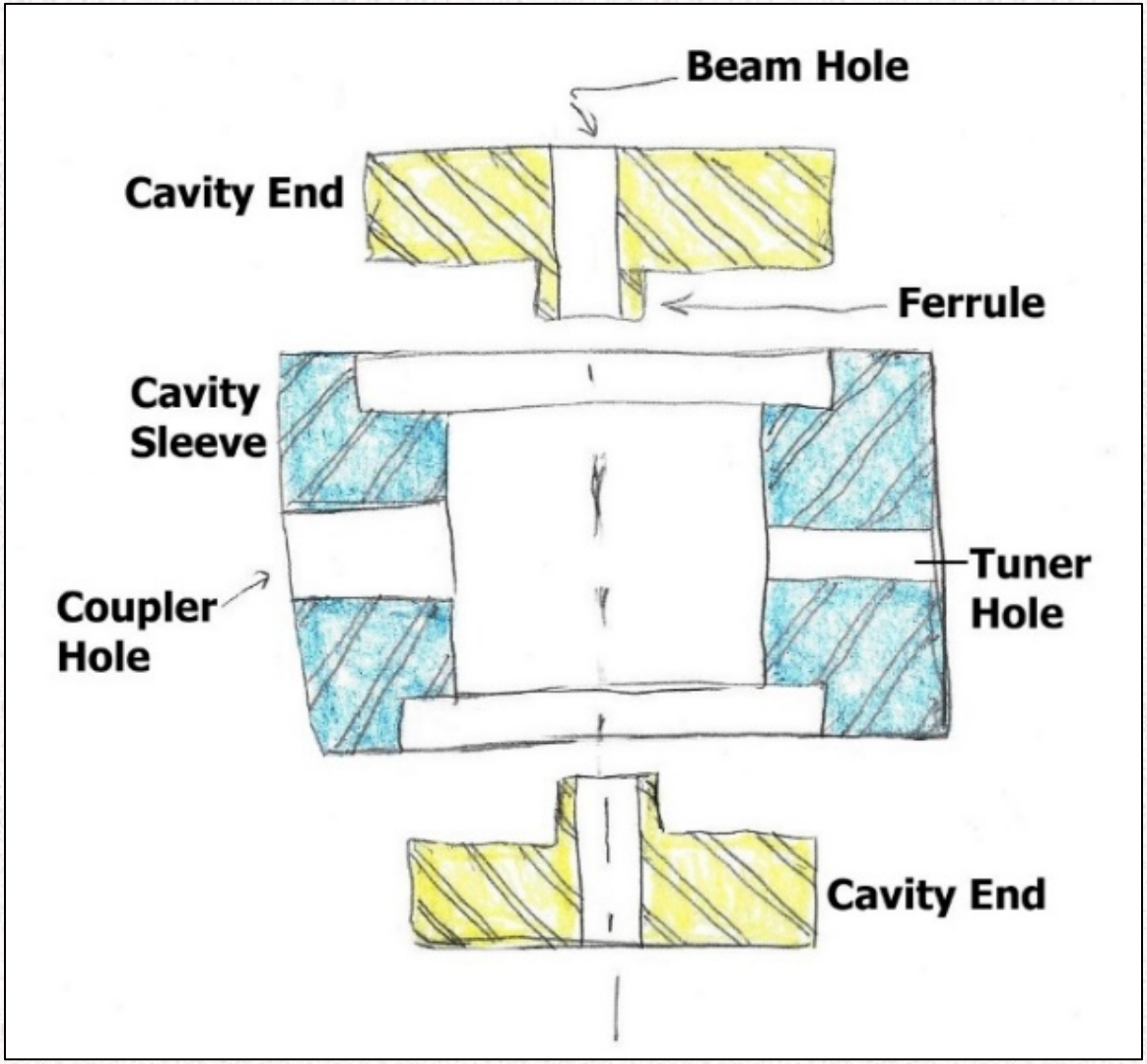
CAVITY/FOCUSING STRUCTURE



CAVITY ASSEMBLY



THREE-PIECE BRAZED CAVITY DESIGN

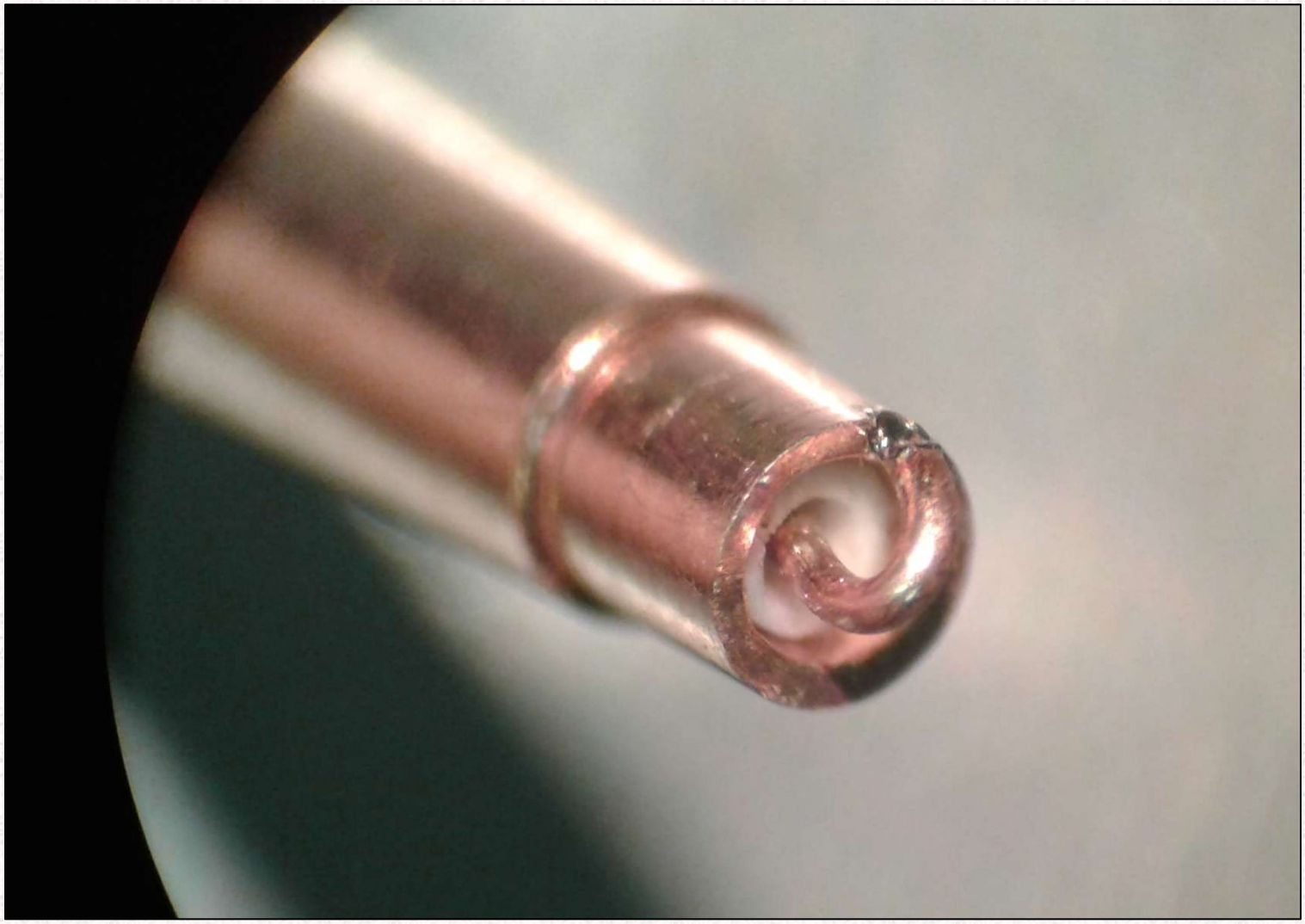


CAVITY ASSEMBLY PIECE PARTS

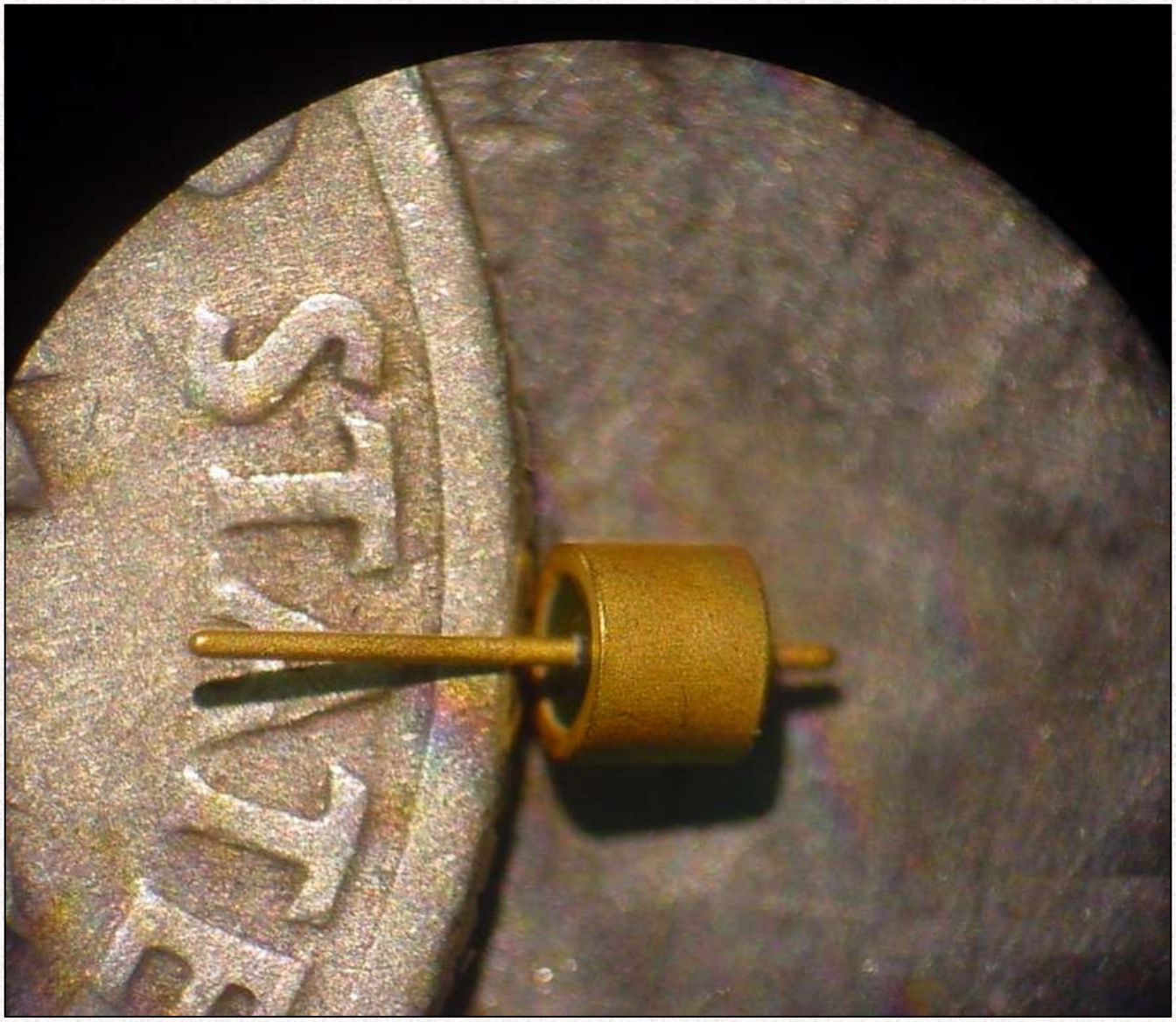
RF COUPLERS/WINDOW/TUNERS

- Coupler loop only 0.5 mm diameter.
- Coaxial window, off-the-shelf glass in kovar sleeve.
- Tuners consist of 0.625 mm pin into tuner orifice, all four cavities.
- Tuning scheme avoids bellows through the glass envelope.

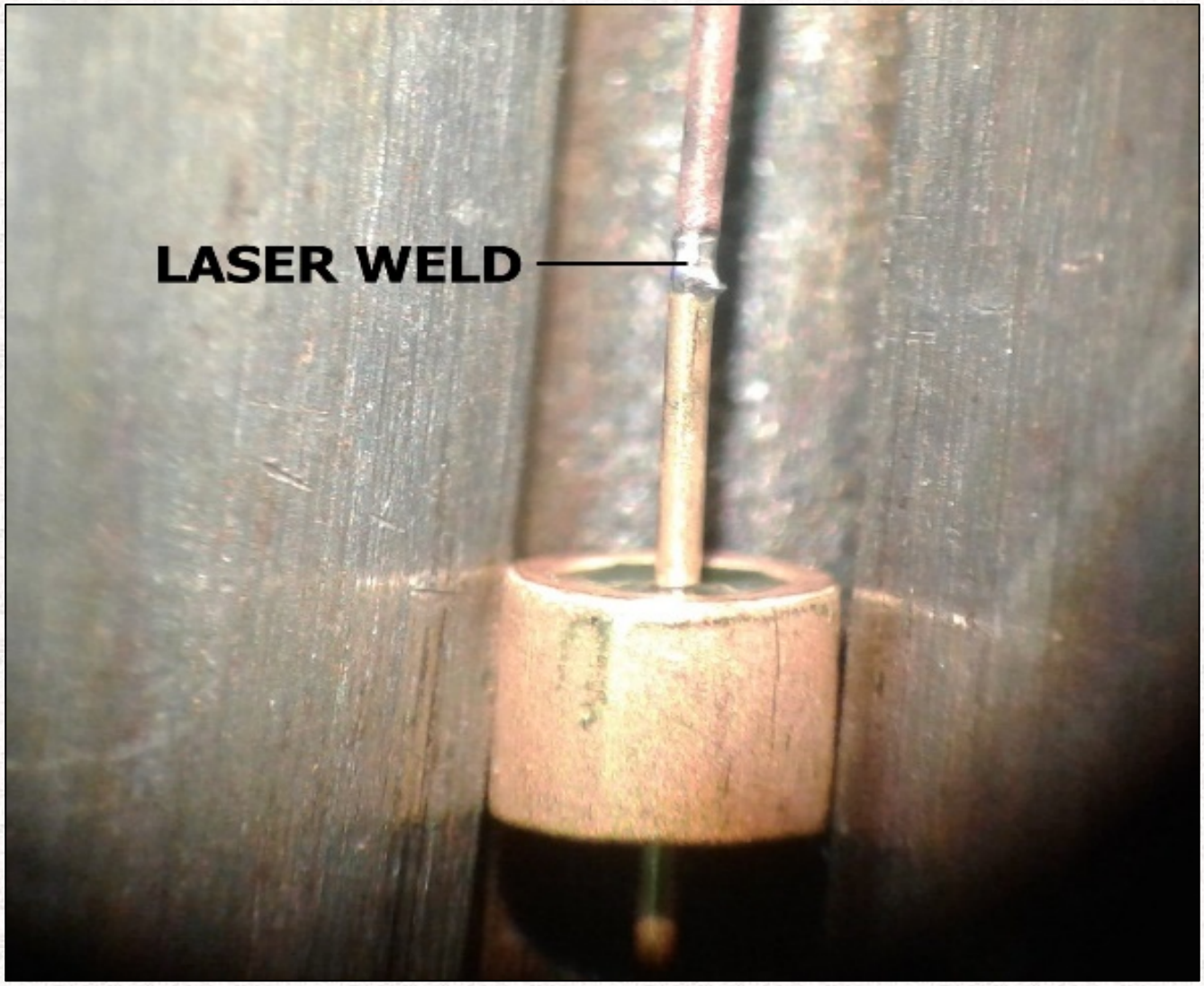
COUPLER LOOP



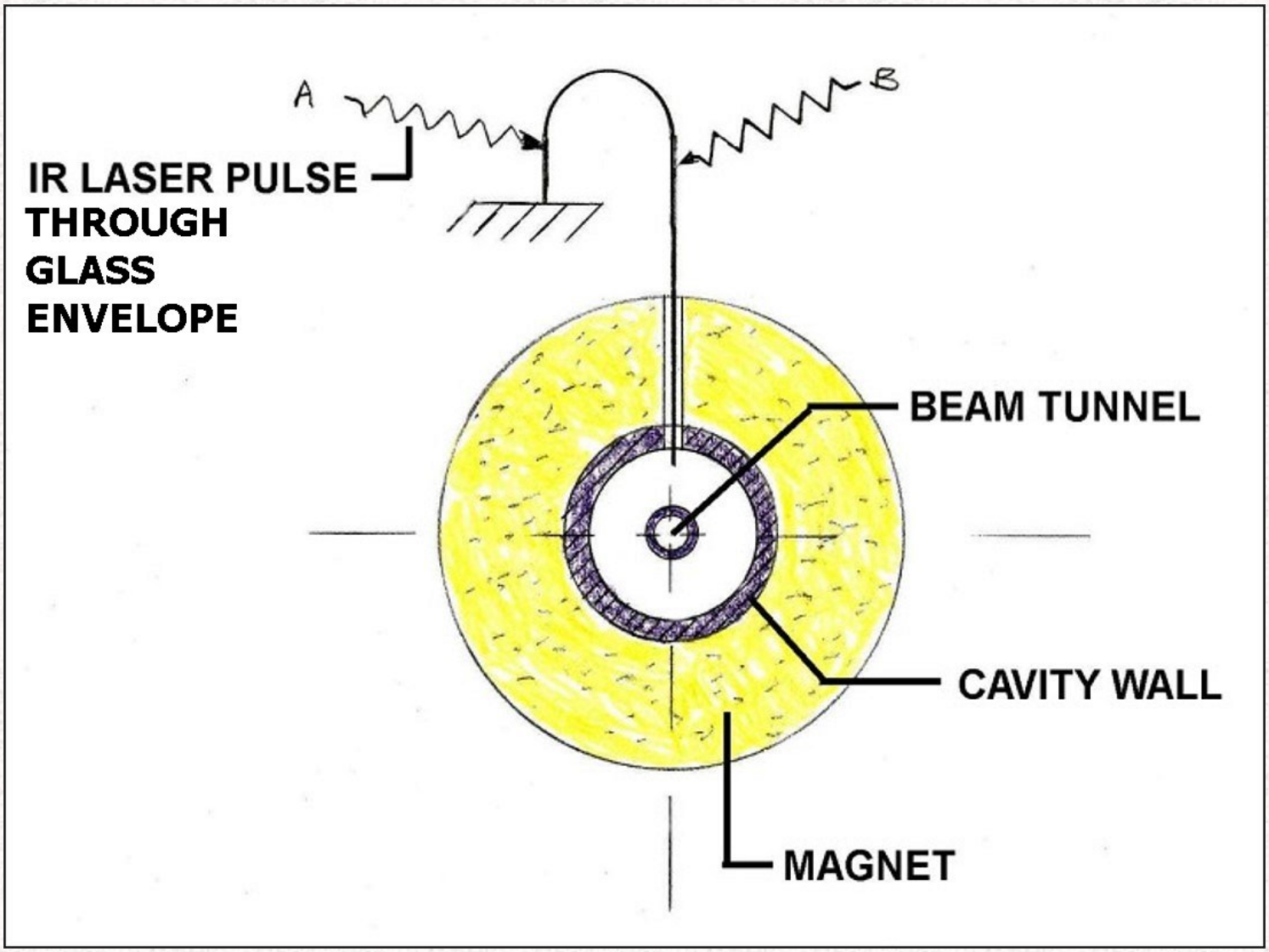
50-OHM WINDOW



COAX MICROWAVE WINDOW



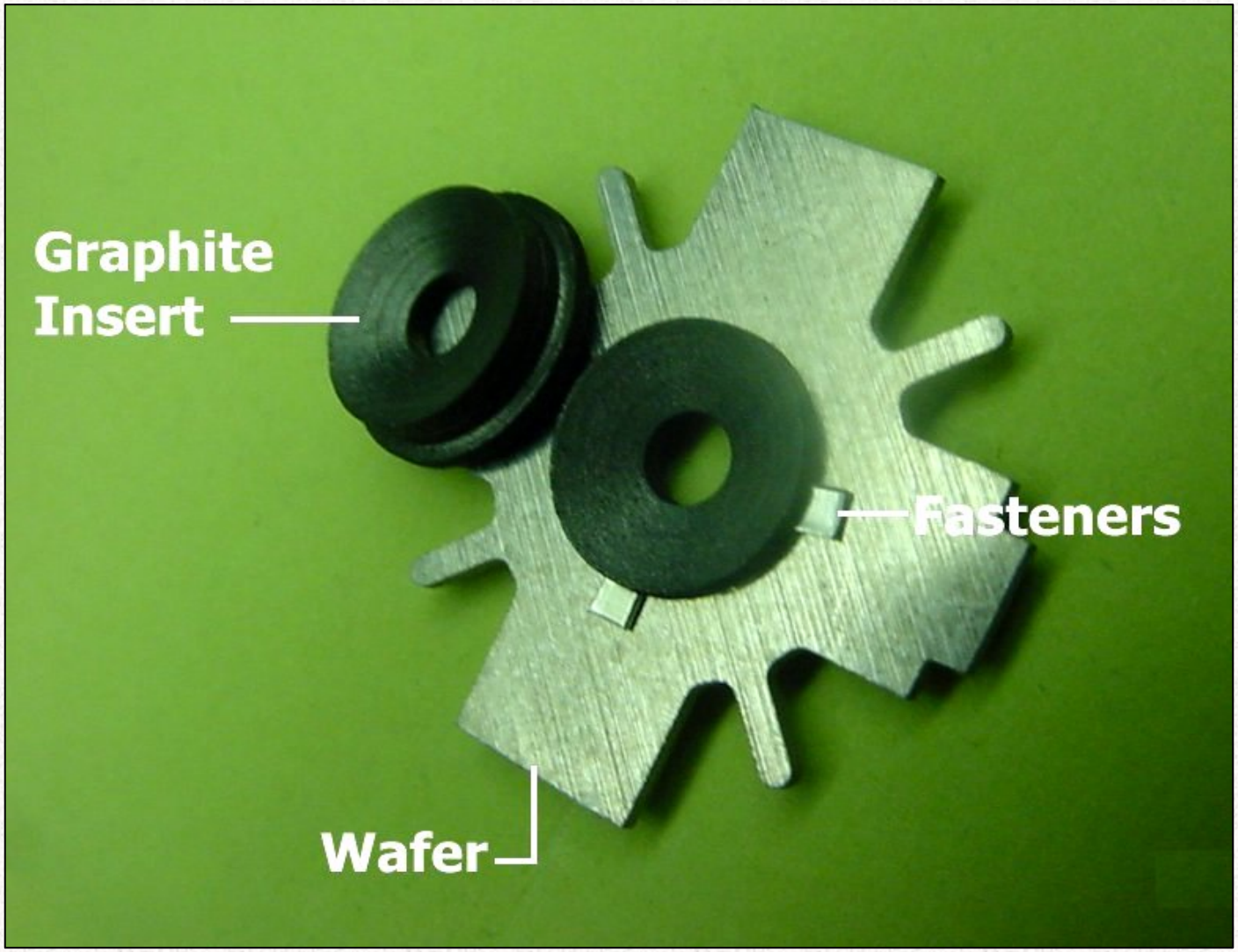
SCREWLESS TUNING SYSTEM



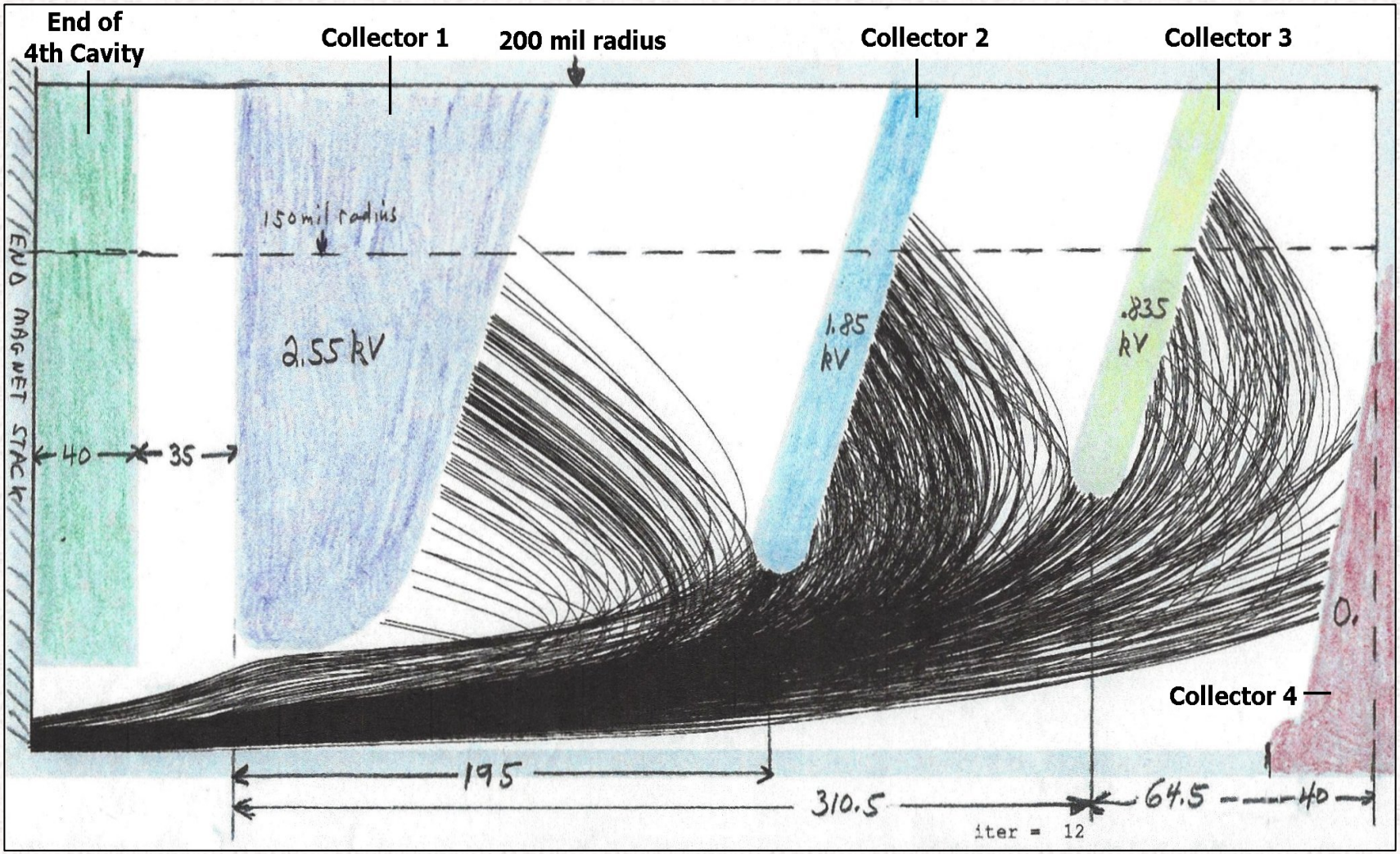
COLLECTOR DESIGN

- 4-Stage depressed collector.
- Collector wiring inside the vacuum envelope.
- Graphite inserts mechanically captured on support wafers.
- Carefully modeled using proprietary code with secondary electrons generated by Monte Carlo technique.

COLLECTOR INSERTS



COLLECTOR LAYOUT WITH PRIMARY RAYS



CONCLUSIONS

- Ohmic Q is a problem at 35 GHz. Over 30% of the RF power was dissipated as resistive cavity losses, especially in output cavity. This hurt gain and efficiency.

- An extended interaction final cavity with two extra intermediate cavities may mitigate this problem.

- Accomplishment: An amplifier of substantial power, low cost and amenable to high volume production.

- This amplifier is small enough in size and low enough in power dissipation to be used in a 1U CubeSat.