NATIONAL HIGH MAGNETIC FIELD LABORATORY

Tools, Materials, and Sandboxes for NMR Probe Building

This presentation is broken into three parts to pass along some practical knowledge from our history of probe building:

- Tools - over the years we have acquired specialized tools we now find indispensable in categories of soldering, hand fabrication, and RF measurement
- Material selections - organized by the probe's anatomy of probe frame parts, and RF circuit components
- Circuit sandboxes - to play with new concepts of RF circuitry before committing to a probe build

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2022 NRANT Probe Building Workshop

FLORIDA STATE UNIVERSITY

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UF UNIVERSITY of FLORIDA

Tools - Soldering Stations

Look for a station with easily replaceable tips and digital temperature control, quick tip heating, and standby mode to extend tip life.

Units that we have from Hakko and JBC heat much faster than our previous soldering stations.

Dual handpiece soldering stations are convenient - adding hot tweezers for soldering chip capacitors.

Budget friendly Hakko FM-203 station with FM-2023 mini hot tweezers

- Can purchase for under $1k
- Avoid FM-2022 tweezers – too large
- For similar-sized tip, heating is slower than JBC
- Many tip styles are available, we can pass along recommended part numbers

Luxury-class JBC NASE-1C nano station with NT115-A handle and AN115-A tweezers

- Cost including tips ~ $1.5k
- Tip heating is very fast
- Tweezers and single tip are smaller (allows for more detail work) and solder stays ‘on pointe’
- Easy programming with color display showing power level

Solder and Flux (and Flux Remover!)

Solder

- We use rosin core tin-lead solder, small diameter of .025 inch is good for detail work and fine for larger parts
- Rosin core flux provides good wetting. Stay away from acid flux core solder – they are not needed for clean electronics components and can lead to oxidation of joint if not properly cleaned
- General soldering: Sn63 / Pb37 rosin core. Melting temperature of 183°C
- Soldering to gold plated solder pads: Sn62 / Pb35 / Ag2. Melting temperature of 179°C

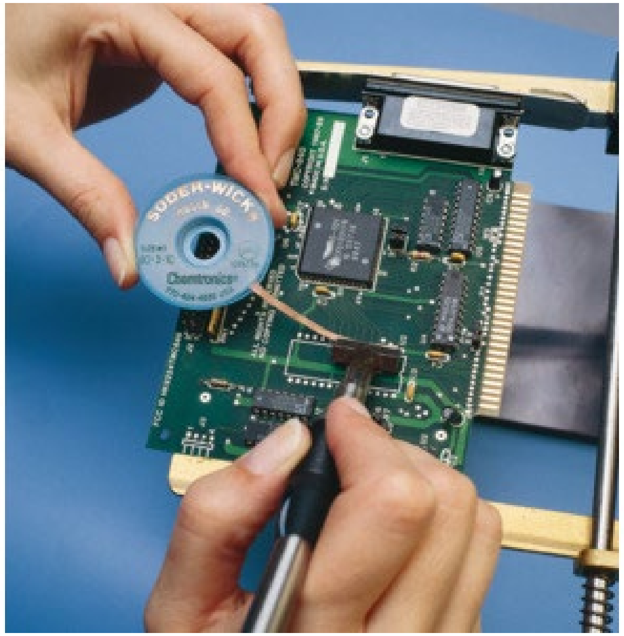
Flux

- Paste flux is helpful for thermal bridging to avoid dry solder tip, reduces time that hot tip is on sensitive components
- We use LA-CO Flux-Rite 90 – non-acid water based paste flux

Flux Remover

- Spray flux cleaner is helpful for getting underneath gaps between soldered components and PCBs
- We use ethanol-based MG Chemicals 4140-400G. It is safe for most plastic, is low odor, leaves no residue

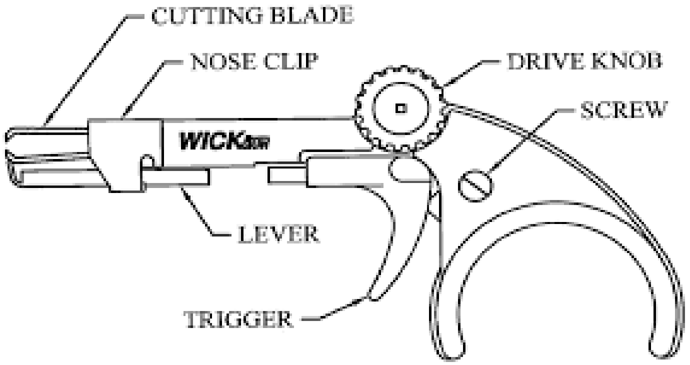
Solder Wick



Useful to remove solder buildup after removing components from PCB’s

Braided copper with embedded flux uses capillary action to remove melted solder

Traditional solder wick spools are cumbersome, require extra step of cutting off used braid



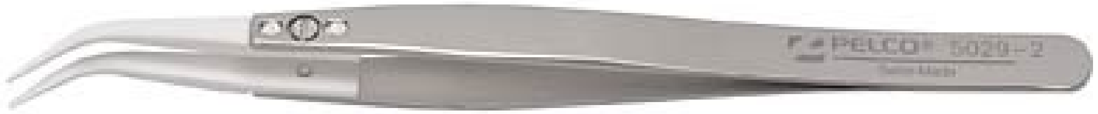
Xuron Wickgun 1000-3

- Built-in dispensing wheel and tip cutter is more efficient
- Replaceable cartridges for different braid widths, we use #3
- Disadvantage – braid sometimes kinks inside gun and requires removal and rethreading of cartridge

Component Handling

Panavise Model 302 with parts tray, useful for soldering and hand fabrication

- cost is approximately $100
- 360° swivel head allows for optimal positioning of workpiece
- replace the stock jaws with Model 352 PTFE high-heat jaws (or copy jaw design and get custom-machined PEEK jaws)
- Vise heads for PCB are available, such as Model 203



Zirconia ceramic-tipped tweezers are a must for handling ceramic chip capacitors

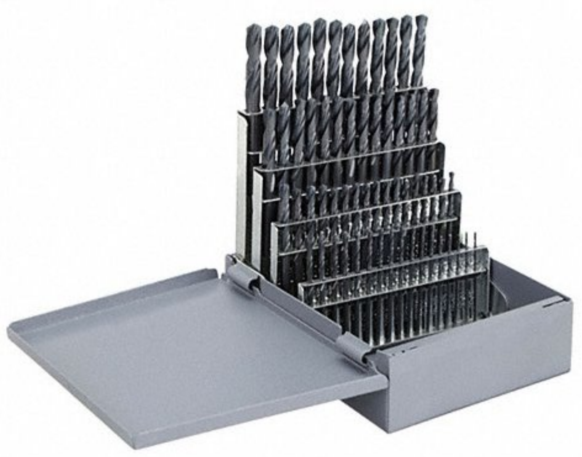
- plain metal tweezers can leave metallic traces on ceramic capacitors (path for arcing!)
- Cost is higher than all-metal tweezers, but we found best price at Ted Pella – PELCO model 5029-2 (~ $55)
- Disadvantage – tips are brittle, will break if dropped
- Replacement tip sets are available ~ $35 PELCO model 5029-2-T

Semi-rigid Coax Stripping Tool

Huber Suhner model 74_Z-0-0-157

- Interchangeable blades for removing jacket of .047, .085, and .141 SR cable
- Adjustable stop to control length of stripped jacket
- List price is expensive at $560, but we have purchased used tools in good condition from Ebay

Hand Fabrication – Hand Drilling and Tapping



1-60 Wire gauge drill bit set and reamer set

- Get good quality **screw machine length** bits. Shorter length means less wandering of small diameter bits.
- A good set is Chicago-Latrobe #69885, ~ $200

General Tools 93 Hand Pin Vise

- Useful for hand-reaming existing holes to larger diameters
- Can use to 'chase' tight threads with tap

Micro-Mark 87362 Tapping fixture

- Parts made by 3D printing will not have threaded holes. We use a tapping fixture to ensure straight threads.
- Small drill bits and reamers can also be used in tapping fixture for hand drilling.

Gauges to check machined and 3D printed parts

Plug Gage Sets

- Class Z (.0001" tolerance) or Class ZZ (.0002") are useful for checking hole sizes.
- Can be used as QA check from engineering drawing *or reverse engineer existing parts*
- Class X 25-pc 10th increment sets for MAS parts
- Good beginner 250 pc set has sizes from 0.110" to 0.250" in .001" increments

Illustrated: a TP25 Tenth set with a .2500" Nominal gage, center. 12 gages, left row, are in .0001" increments RANGING DOWNWARD from the Nominal size. Right row, 12 gages in .0001" increments RANGING UPWARD from the Nominal size

Digital Calipers and Micrometers

- Several good brands, we have had good success with Mitutoyo
- We use 6-inch calipers for every day use
- For precise measurement of probe plugs that insert to tubes we use micrometer for added precision – pay attention to size range for your needs since spindle travel is limited

Telescopic Gages

- Useful for measuring ID of probe body tubes.
- Spring-loaded gage is locked and then measured with caliper or micrometer.
- Multiple measurements are needed since tool must be aligned to tubing axis for accurate measure of diameter

Hand Fabrication – Deburring

Shaviv 154-90081 disposable scraper set

- Essential for removing sharp edges from machined parts.
- Most useful size is the fine blade, # 155-90080
- 90084 ceramic blade useful for plastics (metal scraper cuts too deep) and NMR coils (lack of magnetic contamination

Zero-flute countersinks for holes

- Less aggressive than multi-flute countersinks, results in smoother finish. Sizes from #00, #0, #1
- Available in 60°, 82°, 90°, 120° countersink angle.
- 60° c'sinks are good for adding steep chamfers to hole.
- 82° and 90° match head profile of imperial and metric flat head screws
- 120° match the taper of individual thread profile to add countersink or deburr threaded hole.

RF Bench Tools

LCR Research Pro1 Tweezers ~ $300

- Very useful for measuring trimmers and chip capacitors, both on and off PCB
- There are less expensive LCR tweezers, but these measure down to 0.1 pF with 0.2% accuracy – others do not
- Can use to record chip capacitor values on existing probe, then use to troubleshoot for possible damaged capacitor

USB VNA's

- Connects to PC or laptop, can be 1/3 or less of the cost of traditional benchtop VNA
- Copper Mountain TR1300/1 (1.5 port) 300 kHz to 1.3 GHz ~ $4K
- Copper Mountain "University Kits" variety of USB VNAs at special pricing
  ex: CMT808**U** *4-port* VNA 1 MHz to 8 GHz ~ $9K

Homemade Inductive Pickup Loops

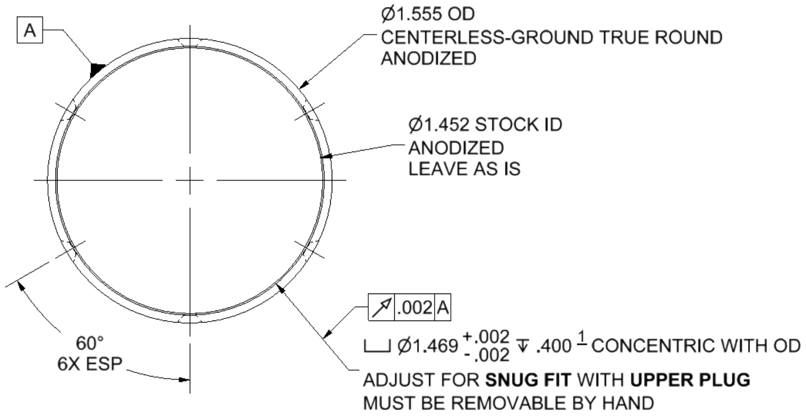
- Combined with VNA to check self-resonance of detection coils and traps
- Easy to make with different size loops from SR cable

Probe frame – body tubes and base

- We make extensive use of aluminum for the structure of our probe frames
- It is lightweight, easily machinable, and a conductive common ground path from SR cable connector attachment to ground plane of RF circuit decks.

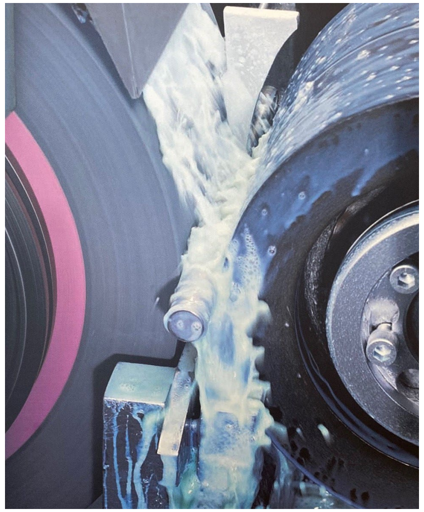
Probe body extension tubes and covers

- 6061 (or 6060 metric) alloy tubing
- 1.5 mm stock wall thickness is enough for resistance to denting while maximizing area for RF components and MAS stators.
- Since Bruker RT shims ID's are sized the same as common OD's of tubing stock, we have to turn down outer diameter of probe tubes. 40 mm shims use 39.6 mm probe tube
- Historically we had to use lathe process - difficult and time consuming to achieve consistent OD along tube length
- We now send stock tubes to centerless grinding shops which yield smooth *and very precise* final OD, concentric to ID.



Probe base parts

- 6061 aluminum bar or plate stock
- Thickness ~ 6 mm with built-in probe legs, and importantly – location for shock absorbing bumpers
- Body extension tubes and base parts are finished with MIL-PRF-8625 Type III hardcoat anodizing. PTFE coating is added to anodizing process to add to durability of probe frame.

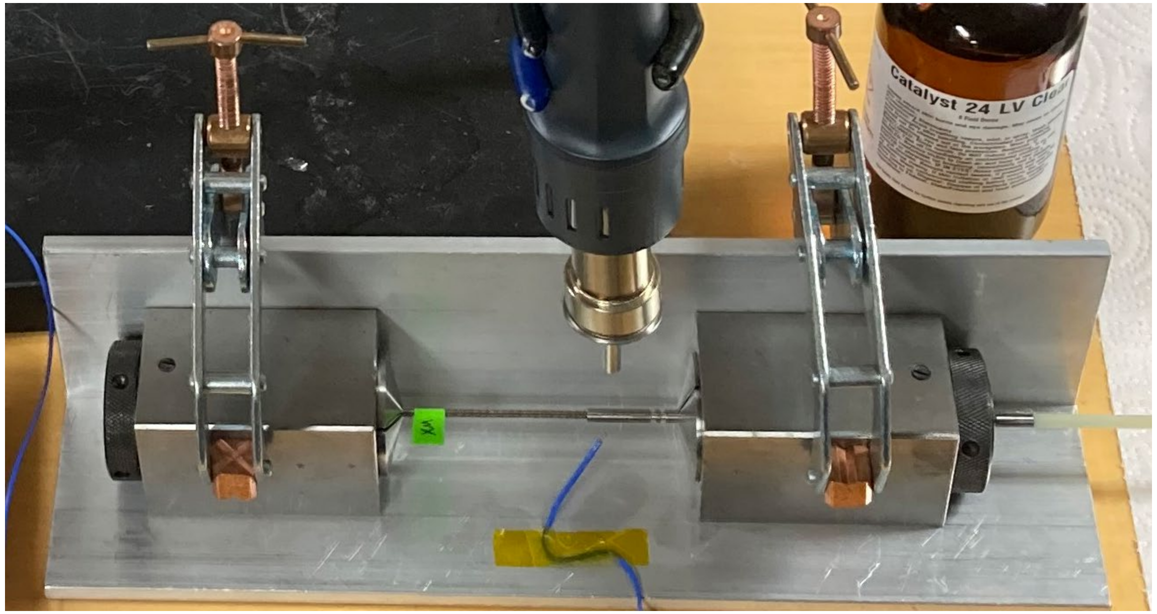


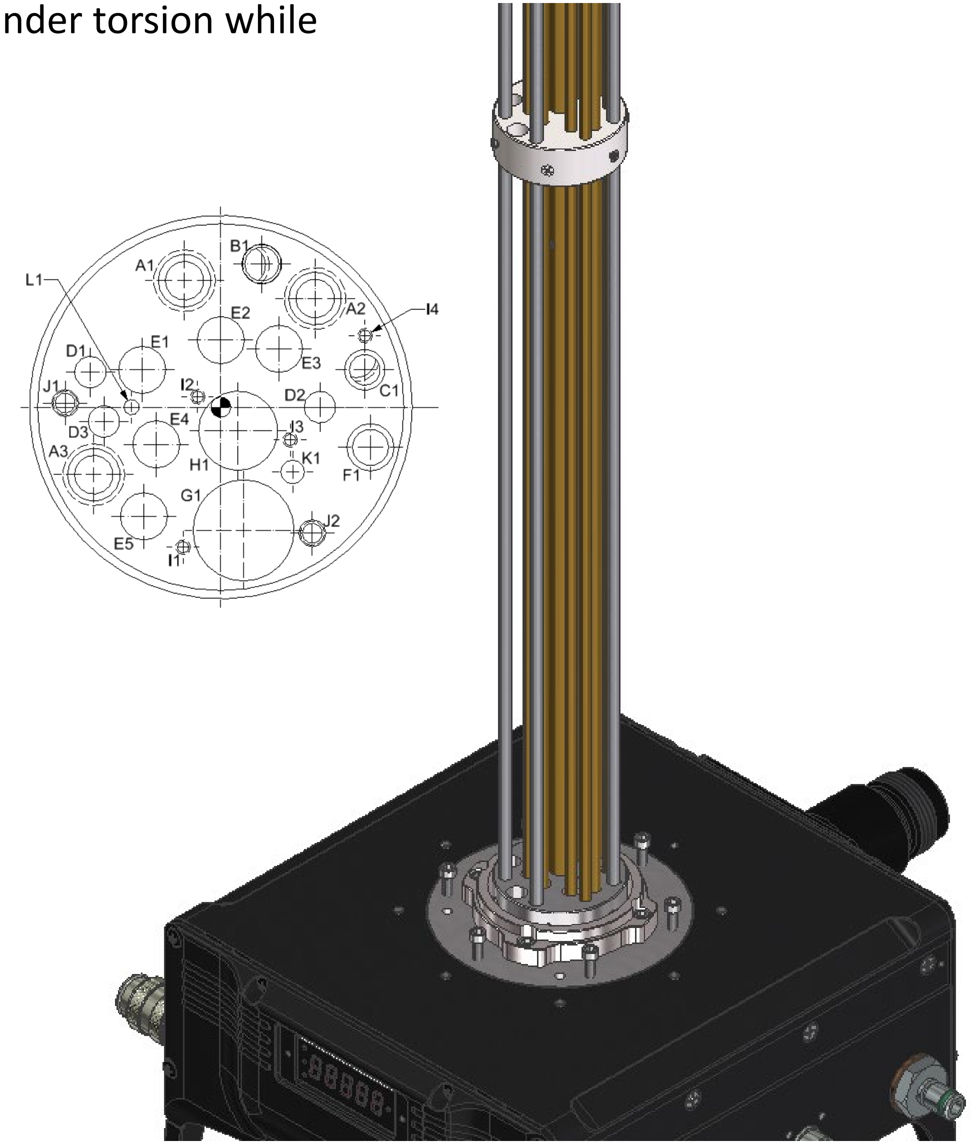
Probe frame – adjustment rods and guide tubes

- These parts are most commonly made from C260 alloy brass telescopic tubing.
- Tubing with 0.4 mm wall is sufficiently rigid to avoid bending under torsion while minimizing footprint and weight.

Trimmer adjustment tube subassembly

- We use Loctite 680 retaining compound to glue non-conductive G10/FR4 extensions to 1/8” OD trimmer adjustment tubes
- Loctite 680 is low viscosity anaerobic compound, dries at room temperature in ~20 minutes (full cure in 24 hrs), rated to -75°C.
- We use 5C collets and collet blocks to concentrically align parts for gluing.





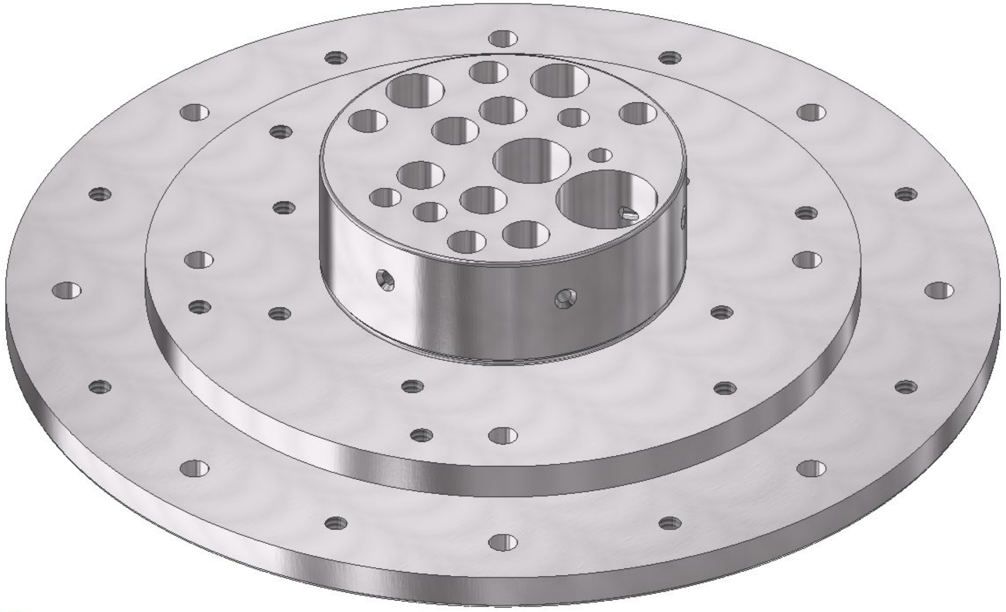
Probe frame – upper and bottom plugs

Upper plugs are made from C360 brass

- C360 brass is strong and easily machinable
- Aluminum is avoided for this part since the aluminum probe cover is a sliding fit – two soft metals sliding against one another = galling
- When plugs are CNC-machined, we can have irregular shaped pocket of removed material to reduce mass of upper plug
- Finished part is plated with “white bronze” alloy (2-3.8 um thk), tri-metal alloy of approx. 55% Cu, 30% Sn, and 15% Zn
- Tri-metal plating is highly corrosion and wear resistant, and non-magnetic
- We have tried bright tin, silver, and cadmium plating in past – tri-metal has the better real-world performance

Bottom plugs are made from 6061 aluminum

- At this location there are no sliding fit parts, so aluminum is used to save weight
- We do not anodize this part so that RF cable clamps and the bare aluminum counterbore of probe body tube provide good ground path.
- At all locations where trimmer adjustment rods rotate in top and bottom plug, we press-fit plastic self-lubricating bushings



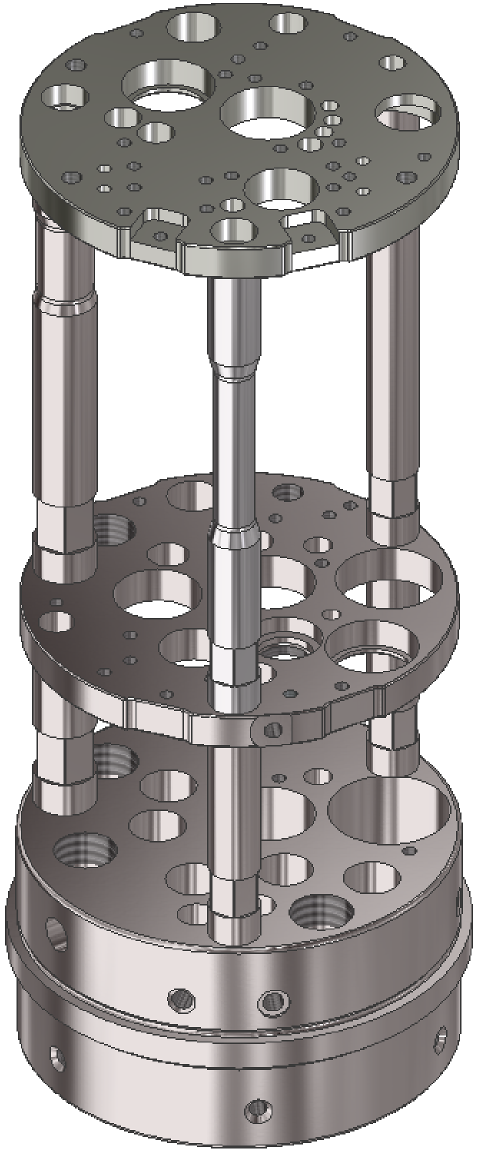
RF circuit decks

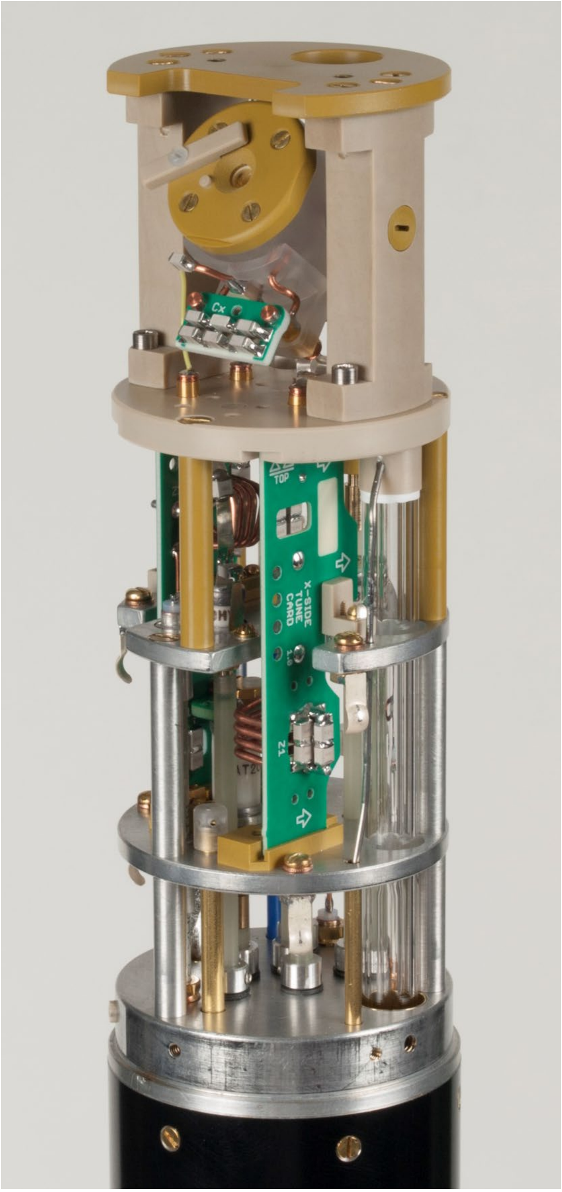
RF component mounting decks are made from C360 brass, sometimes C101, C110, or C145 copper

- Copper decks have been used on some probes where ground resistivity for high frequency is a concern.
- For most of our probes C360 brass is used since part is tri-metal plated – at least 80% of 1H frequency's RF current resides in plating layer

Standoffs are made from C544 phosphor bronze

- Bronze alloys are stronger than brass, while still being nonmagnetic and easily machinable
- For MAS probes, to save real estate we use hollow standoffs to route Bearing gas to spinner – saves the space of having separate pneumatic tube for this purpose
- Our designs use threaded standoffs so that entire probehead is easy to disassemble without desoldering probe frame components

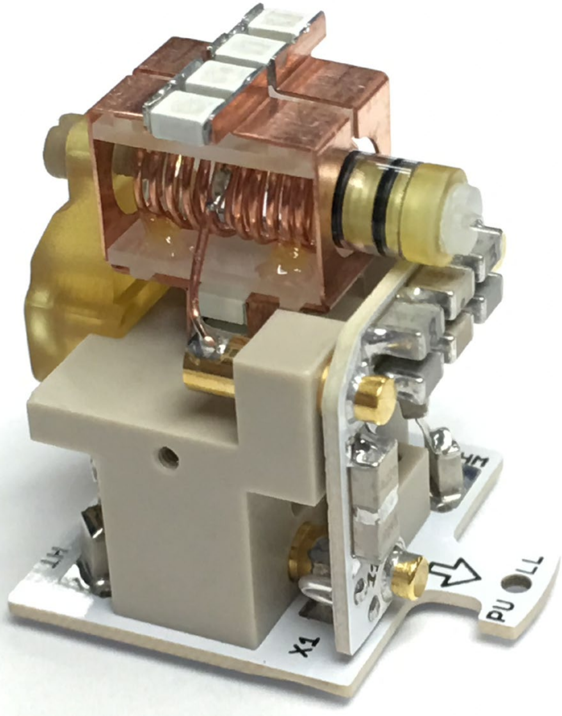


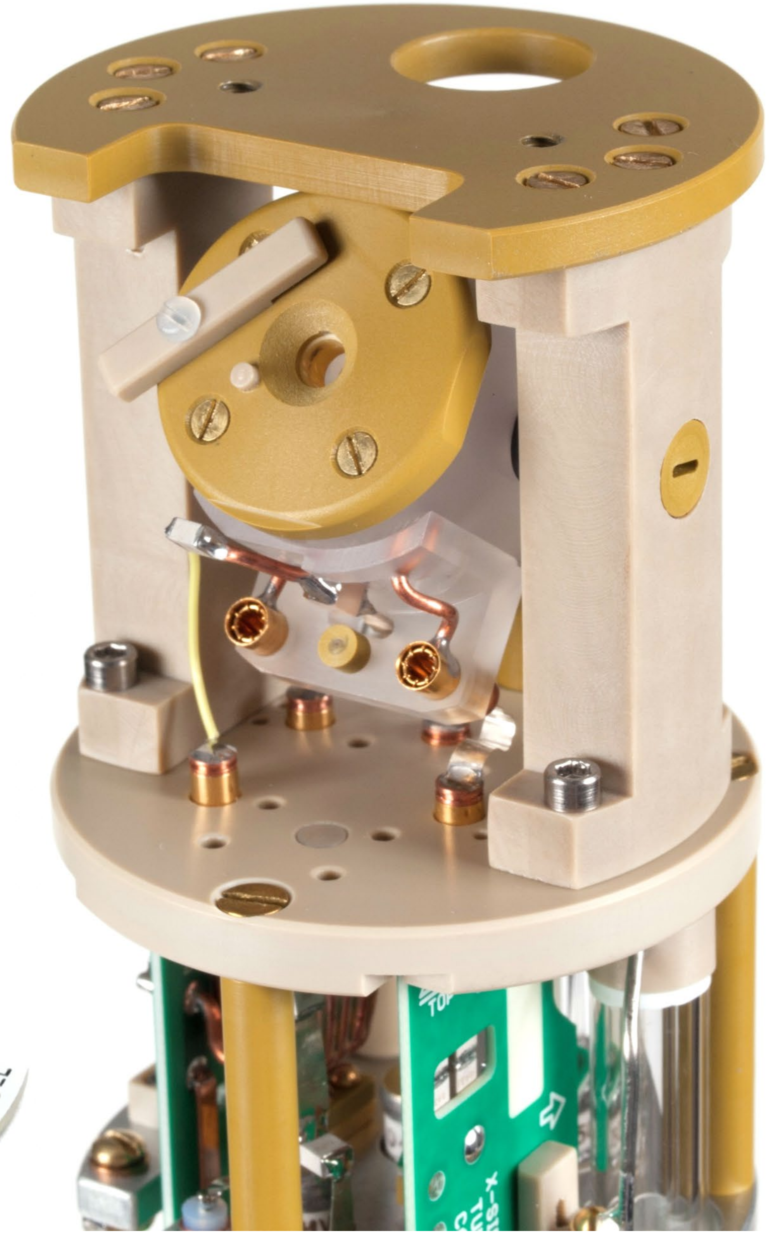


Engineering plastics for RF probehead and VT

We use a variety of engineering plastics best suited for the part's function

- PEEK and 30% glass-filled PEEK (Polyether ether ketone): often used for stator mounts. PEEK machines well and addition of glass fibers strengthens material (since for our design the stator posts integral to probe frame structure where cover attaches)
- 4203 Torlon (PAI polyamide-imide): has similar properties to PEEK with better low temperature performance – widely used in our DNP probe design
- 4301 Torlon: includes bearing grade additives and can be used for MAS stator pivot bushings
- Unfilled Vespel SP-1 (polyimide): another good choice for high and low-VT applications, main drawback is very high cost. Our low VT probes use this for stator housing.
- Kel-F or Neoflon PCTFE (polychlorotrifluoroethylene): this fluorocarbon polymer is useful when avoiding proton background is a concern. We have used it for stator housings, coil mounting platforms, sample containers. RF properties are also good – low dissipation factor
- Rexolite (cross-linked polystyrene): outstanding RF performance, non-lossy, useful as an insulator. We use it to support RF coils on some static low-E probes

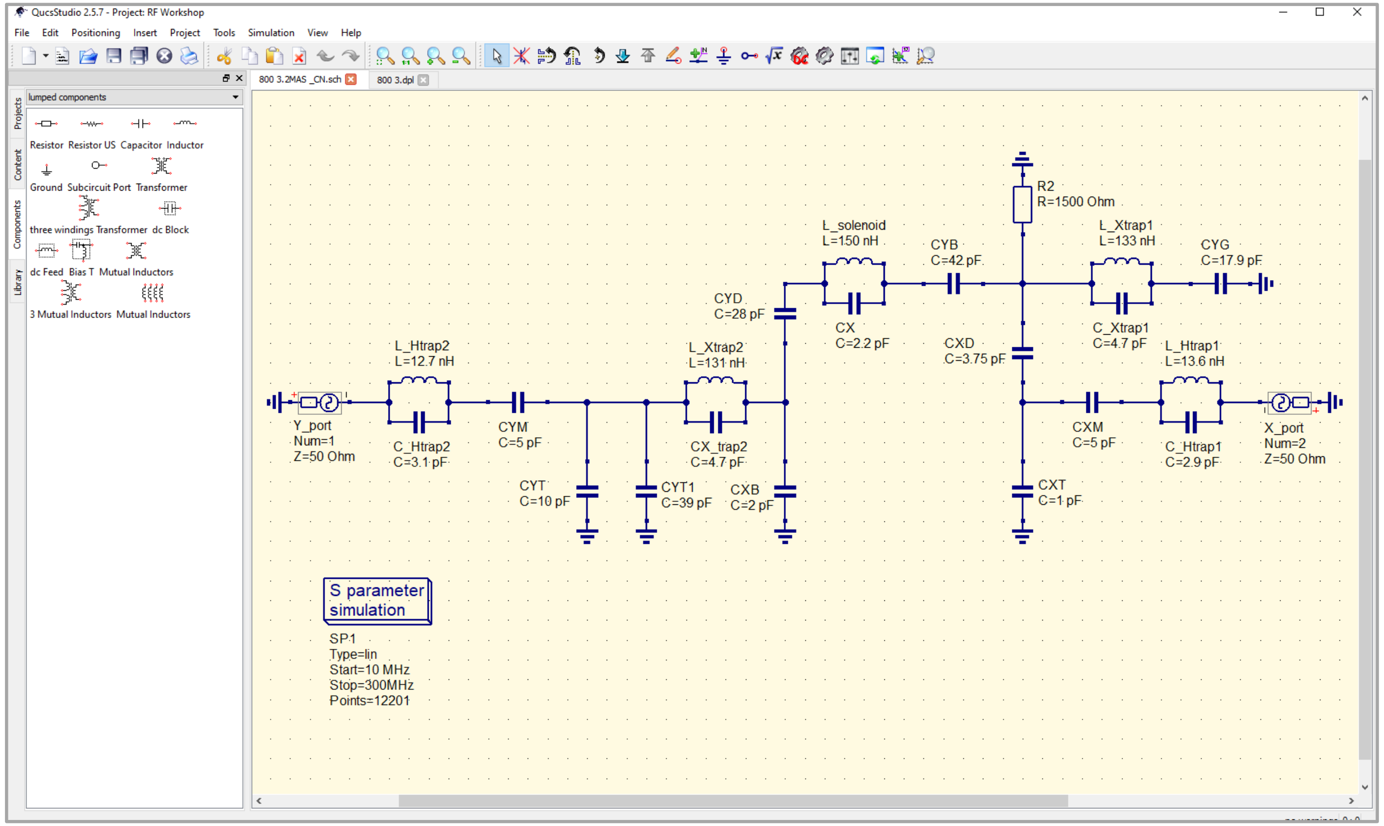


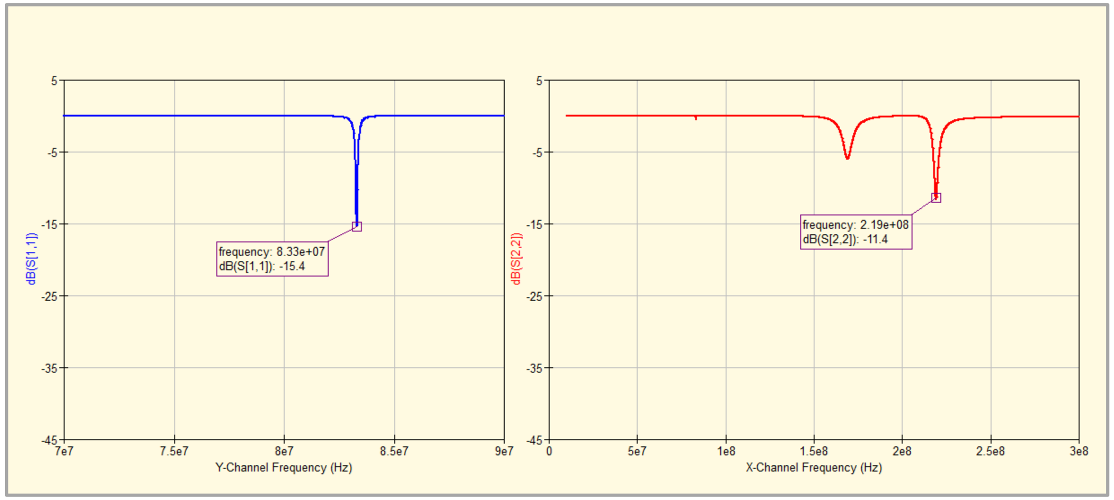


Sandbox for prototype RF circuits

Using metal “Bud boxes” we can try new circuit strategies before building a probe around them. This example shows the XY portion of our Low-E circuit

- First step is to create a simulation of circuit to verify concept. Qucstudio 2.5.7 was used for this circuit – available free and can plot frequency domain S-parameters.
- Qucstudio uses schematic representation, helpful for error checking but can take longer to lay out on screen.
- This example is tuning for 13C-15N for 800 MHz proton. S11 plots show dips close to expected frequencies of 201 MHz and 81 MHz





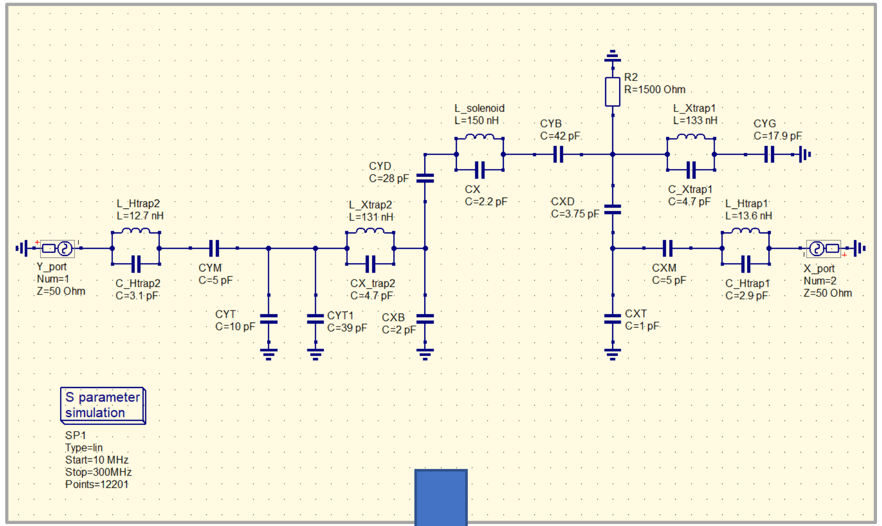
83.3 MHz

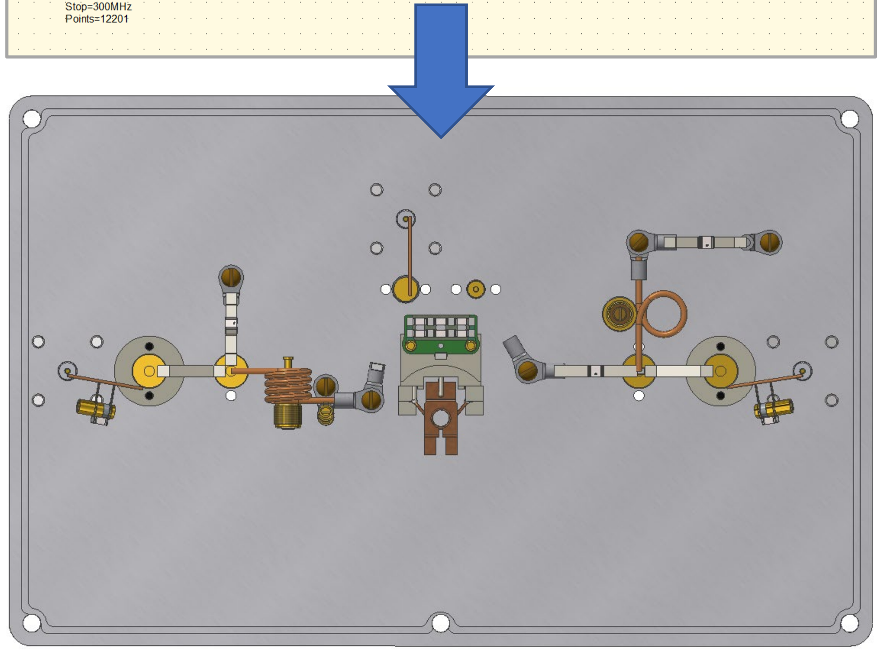
219 MHz

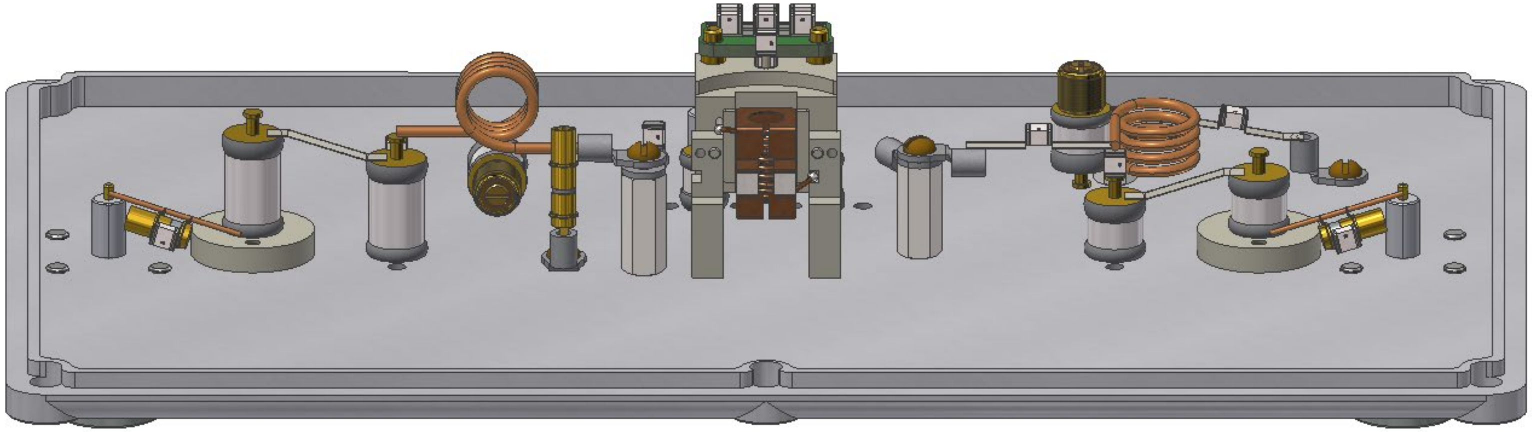
CAD modeling of sandbox circuit

The lid of Bud box can easily be drilled to mount lumped elements of circuit, best practice is to create a CAD model

- CAD model allow us to move components around on 2D plane and approximate distances between components on actual probe (important since long leads can have standing waves)
- We use free educational license of Autodesk Inventor – software has all features of commercial license
- Over the years we have built a library of “standard parts” like capacitors, screws, and standoffs shown below which speed up modelling
- Model can easily be used to generate engineering drawings, and converted to CAM files







Construction of Sandbox

Once the lid is drilled and holes tapped, placing components and soldering completes construction

- We use variable capacitors in RF traps and for circuit balancing so that these can be adjusted based on VNA plot results
- There is no need for high voltage or nonmagnetic trimmers, but we use ones with similar maximum capacitance as the final components that will populate probe
- Ease and speed of assembling sandbox allows for circuit testing within a few days
- For this workshop we have three boxes for you to assemble and practice soldering and tuning