

Long Lab



Technical Note  
T20-002  
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## Electronics for August 2020 Target Stick

E. Long (UNH)

### Abstract

The August 2020 target stick re-uses much of the same stick used during the December 2020 cool-down that is described in M. Boer's 'Target Ladder Information' technical note. However, the second NMR has been disconnected, the third cup has a new 'cold board' installed, and some of the thermometry has changed. This document outlines these changes, includes current electronics schematics and maps, and provides some basic tests that can be done to analyze problems.

## NMR Top "UFO" Ports

- 1 =  $\circ$  = Top Araldite Cup
- 2 =  $\circ$  = Cold NMR Board Input
- 3 =  $\circ$  = Cold NMR Board Output
- 4 =  $\circ$  = RF Hole Burning

Figure 1: Numbering and labels on the NMR ports on the top of the target stick.

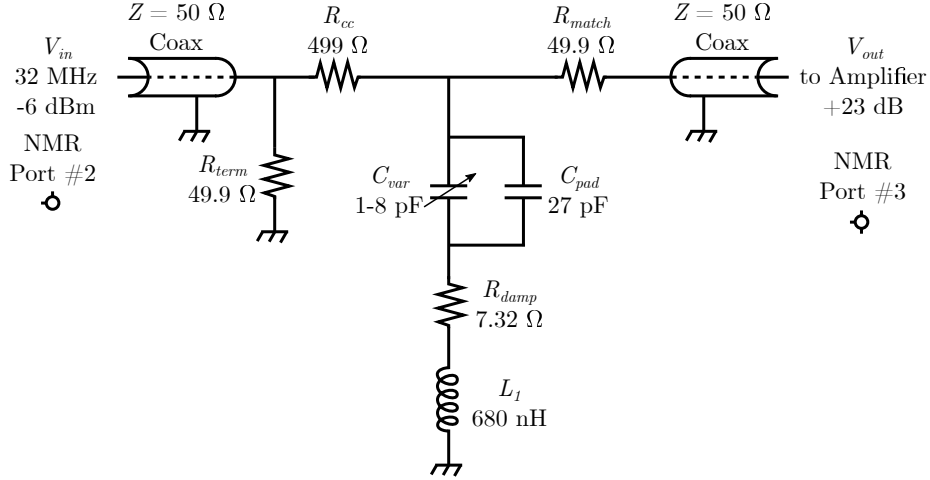


Figure 2: Schematic of the cold-board electronics in the current target stick.

## 1 NMR System

There are four NMR ports on the top of the target stick (the so-called 'UFO' ports) that connect to the small top cup that contains an NMR coil embedded in Araldite for proton measurements, two ports connect to the newly-installed LANL cold NMR board in the third cup, and the fourth port connects to the RF hole burning coil wrapped around the third cup. The second target cup has not been removed, though the NMR coil in that cup has been disconnected in order for the cold NMR board to work. These ports, along with the markings on the ports themselves, are given in Fig. 1.

Since the cold NMR board is connected to the third target cup, it can be used to ensure that all of the NMR cables are connected properly utilizing a simple Ohmmeter. The electronics schematic is shown in Fig. 2. Since all of the NMR cables and the RF hole-burning cable share the same ground connection, which is the same ground plane as the entire metal portion of the 'UFO' top of the target stick, measuring the resistances across the different NMR port pins and the shared ground will give values shown in Table 1.

### 1.1 SDR-Kits VNA

The cold NMR board is a 2-port device, so it can only be used with a 2-port VNA such as the SDR-Kits VNA. Fig. 3 demonstrates the two sides of a 2-port network, such as the NMR cold board, and defines an input ( $i_1$  or  $i_2$ ) and an output ( $o_1$  or  $o_2$ ) on each of the

Table 1: Resistance measurements across the pins and shared ground of the NMR cables when they are properly connected. These may change slightly when immersed in cryogen.

1 <sup>st</sup>	2 <sup>nd</sup> Pin	$R_{\text{meas}} (\Omega)$
1	2	50
2	3	548
3	4	598
1	3	598
1	4	1
2	4	50
1	Ground	0.7
2	Ground	50
3	Ground	598
4	Ground	1

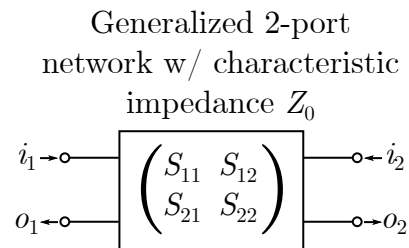


Figure 3: S-parameters of a generalized 2-port network are defined by the reference input port ( $i_1$  or  $i_2$ ) and the signal output port ( $o_1$  or  $o_2$ ). The entire left side indicates a single port (Port #1) and the right side also indicates a single port (Port #2).

two ports. If each port is properly matched to the characteristic impedance  $Z_0$ , which is  $50 \Omega$  for our NMR cables, then the measurable  $S$ -parameters are defined by

$$S_{11} = \frac{o_1}{i_1} \tag{1}$$

$$S_{12} = \frac{o_1}{i_2} \tag{2}$$

$$S_{21} = \frac{o_2}{i_1} \tag{3}$$

$$S_{22} = \frac{o_2}{i_2} \tag{4}$$

Essentially, the first subscript says which port does the measurement and the second subscript says which port sends in the reference signal, which can be roughly thought of as  $S_{oi}$ .

For the cold board and the SDR-Kits VNA, this means that the transmission port of the VNA (TX Out) should connect to the input port of the cold board (NMR port #2) and that the receiver port of the VNA (RX In) should be connected to the output port of the cold board (NMR port #3).

To calibrate the SDR-Kits VNA for 2-port measurements, it's recommended for first create a wide 'Master Calibration' and then smaller calibrations for the measurements. To create a Master Calibration, set a wide frequency range (typically either 1-250 MHz or 1-50 MHz) then either hit the 'C' key or use the menu to go to "Measure/Calibrate". After completing the calibration procedure described below, you can save this wide calibration as a "Master Calibration" file. Note that this must be saved in the folder C:

VNWA or it won't work properly. Any time the frequency is changed, it will interpolate between the Master Calibration points as a 'best guess' at the calibration, making it very useful for tuning. Before doing a measurement, set your frequency range as designed and then run through the calibration procedure below again, though don't save it as a 'Master Calibration'. It's good practice to do a new calibration any time you change the frequency range. The frequency range can be changed by either using the 'Alt+F' shortcut or by using the menu to go to 'Settings/Frequency Range/Linear Sweep'.

Complete the Short, Open, Load calibration by putting the correct termination on the TX Out port. For Short, that's the one that is entirely brass – it creates a short from the outer ground to the inner pin. For Open, don't connect anything. For Load, connect the  $50 \Omega$  terminator that has a pin separated from ground with a white Teflon ring (you can also check it is a  $50 \Omega$  resistor with a multimeter). For the Through measurements, the Cross-Check is done without anything connect to either port, and both of the Through calibrations are done by connecting the TX Out and RX In ports to each other with a small Male-Male SMA cable. If you forget what you need to connect, when you click that type of calibration it will tell you what is needed to connect.

If the VNA displays a 'No Sync Found' error in large red letters, use the menu to go to 'Options/Setup' and on the 'USB Settings' tab click 'Test USB Interface'. If this passes, it usually fixes the problem and you can exit the menu. If it doesn't, go to 'Audio Settings' and click 'Auto-Setup Audio Devices', which will indicate whether there's an error and how to fix it. If you need to click the 'Auto-Setup Audio Devices' button, it will destroy your

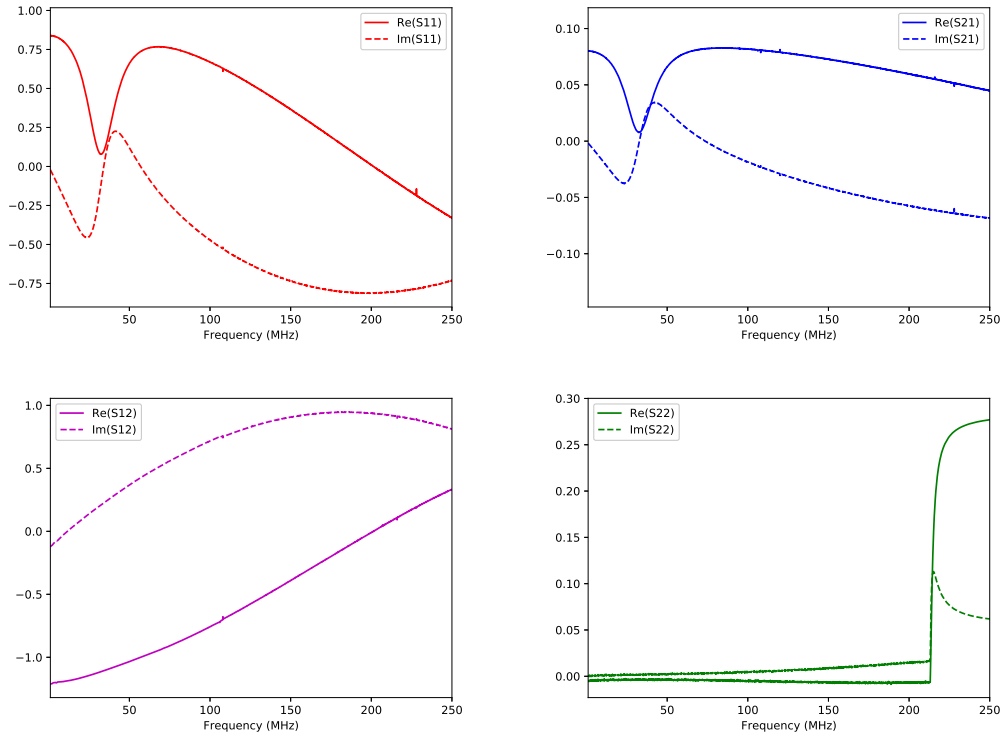


Figure 4:  $S$ -parameters measured from connecting David’s cold NMR board directly to the SDR-Kits VNA. Measurements shown were taken from 1-250 MHz. The tuned 32 MHz resonance can be seen in both  $S_{11}$  and  $S_{21}$ , though the most important measurement will be the real part of  $S_{21}$ .

calibrations and you’ll need to run them again before taking a measurement. The full audio setup procedure is outlined in the SDR-Kits manual starting on page 11 in section 3.2.5, which can be found at <http://www.sdr-kits.net/documents/VNWA%203%20Manual%20W7%20-%20XP%20v2.04final.pdf>.

Once working and calibrated, if you put David’s cold NMR board into the input and output of the VNA and record the  $S$ -parameters, you should see plots similar to those shown in Fig. 4. When connected to the full system including the  $n\lambda/2$  cables, you will see a more complicated plot as shown in Fig. 5. As-of writing, we are still working on how properly tune the cold NMR board given this complex overlap of the response from the cold NMR board and the response from the  $n\lambda/2$  cables. Ideally, you do not want the tuned response curve to accidentally be canceled out.

To save results, you can either do so for individual sweeps by clicking ‘File/Export Data/S2P/Real-Imag’ or you can set it up to record every sweep automatically by clicking ‘Options/Setup’, navigating to the ‘Misc Settings’ screen, and turn ‘Data Logging ON’ and selecting a folder to save it to. **This should only be turned on while you are actively doing NMR and turned off afterwards!!** Otherwise it will create a massive number of files that will be difficult to parse through after the fact. **It’s also important to save**

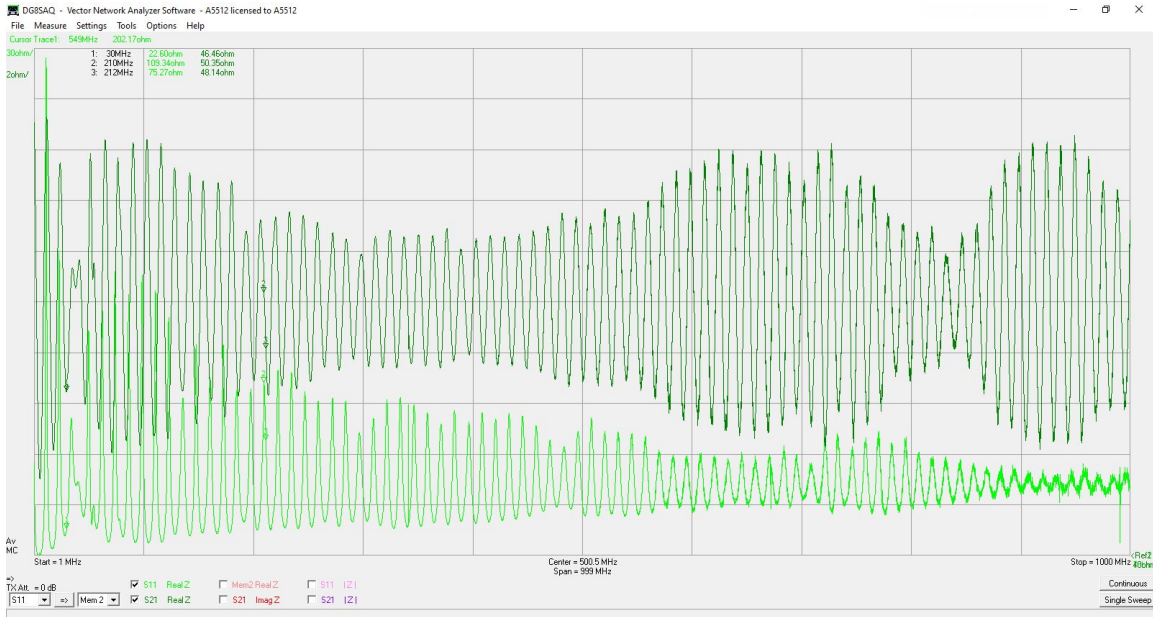


Figure 5:  $S$ -parameters measured from connecting the full cold NMR board system in the target stick, including the  $n\lambda/2$  cables, directly to the SDR-Kits VNA. Measurements shown were taken from 1-1000 MHz.

**file as \*.s2p files to record the  $S_{21}$  parameter needed for the cold board!**

It's good practice to double-check that the \*.s2p files are saving correctly before attempting NMR. When opened with a basic text editor, a \*.s2p file should have nine columns referring to the following, respectively: Frequency (MHz),  $\text{Re}(S_{11})$ ,  $\text{Im}(S_{11})$ ,  $\text{Re}(S_{21})$ ,  $\text{Im}(S_{21})$ ,  $\text{Re}(S_{12})$ ,  $\text{Im}(S_{12})$ ,  $\text{Re}(S_{22})$ , and  $\text{Im}(S_{22})$ . If you display each of these on the screen (which you can do by right-clicking on the live plots and choosing 'Trace Options' and choosing your  $S$ -parameter of interest and 'Real Part' or 'Imaginary Part' in the drop-down menu), you can make sure your file saved properly by running the sparam.py script found in 'Box/UNH Poltarg/dnp\_system/VNA Data Check'. You'll have to copy your \*.s2p file to that folder and edit sparam.py to point to your file, but when it runs it should display the same data that you see on the live-screen.

To look at the proton using either the top Araldite cup or the RF hole-burning coils around the bottom cup, we only need to use the  $S_{11}$  parameter, and thus can calibrate it using only the Short/Open/Load calibrations described above. The appropriate NMR coil, as determined by Fig. 1, should be plugged into the TX Out port. It should be fine to also save these as \*.s2p data files, where we'll only use the  $S_{11}$  columns, but it's always worth double-checking that they are saving correctly. If you have trouble saving  $S_{11}$  with the \*.s2p files, you can save it as an \*.s1p file instead, which will only save the real and imaginary parts of  $S_{11}$ . However, the Copper Mountain Technologies (aka 'Silver Lizard') VNA is more powerful than the SDR-Kits one, and will give a far better proton signal because of this. Follow David's protocols for using that VNA through LabView, though the above advice regarding calibration is still valid.

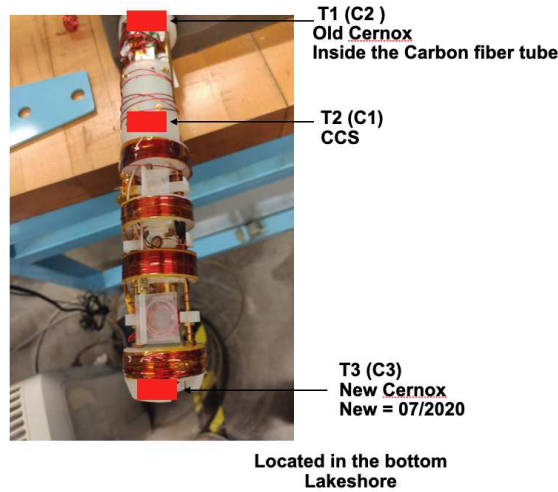


Figure 6: Diagram of the three thermometers in the target stick.

## 2 Thermometry and EPR Coils

There are three thermometers inside the target stick: an upper Cernox (T1) inside of the carbon-fiber tube, a CCS (T2) that sits at the top of the ladder just above the top EPR coil, and a lower Cernox (T3) that sits at the very bottom of the target ladder. These are shown in Fig. 6.

The target stick thermometry comes out of the 19-pin connect on the top of the target stick. That is connected via small cryogenic wires down to a female HDMI connector at the top of the target ladder, which connects to a male HDMI connector and the remainder of the cryogenic wires go down to the thermometers. The EPR coils also connect through the HDMI port and 19-pin connector in a similar manner. There is a special case of the upper calibrated Cernox (T1), which is connected directly to the 19-pin connector and does not feed through the HDMI ports.

After exiting the 19-pin connector at the top of the target stick, the thermometry goes into a DB-25 connector that connects to a pin-out board that makes it easy to test the thermometry and to connect it to the proper cables for sending it to the Lakeshore for measurement.

When correctly connected and at room temperature, the resistances across the following pins on the DB-25 connector should read as shown in Table 3.

The top Cernox (T1) is calibrated, with model number CX-1030-SD-HT-0.3L and serial number X141509. The bottom Cernox (T3) is calibrated, with model number CX-1030-AA-0.3L and serial number X156324. Using these numbers, their calibration data can be found at [www.lakeshore.com/sensors](http://www.lakeshore.com/sensors).

The CCS (T2) is calibrated, and is CCS #981. Note that there is a small possibility that I wrote that number down incorrectly and it's actually either #980 or #3.

Table 2: A list of the thermometry and EPR connections in the target stick including their name, identifier on the Lakeshore, wire colors on the cable outputs to the Lakeshore (thermometry) and signal generator (EPR), pin numbers on the DB-25 connector, and pin numbers on the HDMI connectors.

Name	Lakeshore	Wire Color	DB-25 Pin	HDMI Pin	Component
T1	C2	Brown	1	N/A	Top Cernox (+)
T1	C2	Brown/White	2	N/A	Top Cernox (+)
T1	C2	Orange	3	N/A	Top Cernox (-)
T1	C2	Orange/Black	4	N/A	Top Cernox (-)
T2	C1	White	7	17	Upper CCS (+)
T2	C1	Red/Black	8	16	Upper CCS (+)
T2	C1	Red	6	19	Upper CCS (-)
T2	C1	Green	20	18	Upper CCS (-)
T3	C3	Pink/Black	10	1	Bottom Cernox (+)
T3	C3	Gray	11	2	Bottom Cernox (+)
T3	C3	Pink	9	3	Bottom Cernox (-)
T3	C3	Gray/Black	12	13	Bottom Cernox (-)
EPR	N/A	Red	13	4	EPR Coils
EPR	N/A	Black	21	14	EPR Coils

Table 3: Measured resistances across various pins in the DB-25 connector when the target ladder is at room temperature.

Pin #	Pin #	$R$ ( $\Omega$ )	Component
1	2	13.5	Cernox T1
3	4	14.0	Cernox T1
1	3	54.3	Cernox T1
1	4	53.8	Cernox T1
2	3	54.4	Cernox T1
2	4	54.0	Cernox T1
10	11	0	CCS T2
9	12	0	CCS T2
9	10	1020	CCS T2
9	11	1020	CCS T2
10	12	1020	CCS T2
11	12	1020	CCS T2
8	7	17.5	Cernox T3
6	20	18.5	Cernox T3
7	20	55.6	Cernox T3
8	20	55.6	Cernox T3
7	6	55.6	Cernox T3
8	6	55.6	Cernox T3
13	21	12.1	EPR Coils