Portable NMR System Manual

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Contents

1 Introduction

This is a document detailing the construction and operation of the new portable NMR system. This system was designed as a smaller, portable, alternative to the Liverpool NMR system already in use in Room 28.

The purpose of this document is to provide an up to date manual on the NMR system as a whole. It is written for the new graduate student of the Polarized Target Group who has little or no knowledge of the NMR system and its operation.

A brief outline of the document is as follows. Section 2 details each component of the NMR rack. Details about "the box" are discussed in Section 3. Section 6 is about connecting the components of the NMR system. The Q-meter and Yale card are covered in Sections 4 and 5, respectively. The LabView PDP software is discussed in Section 7. Instructions for tuning the NMR system are given in Section 8.

2 NMR Rack

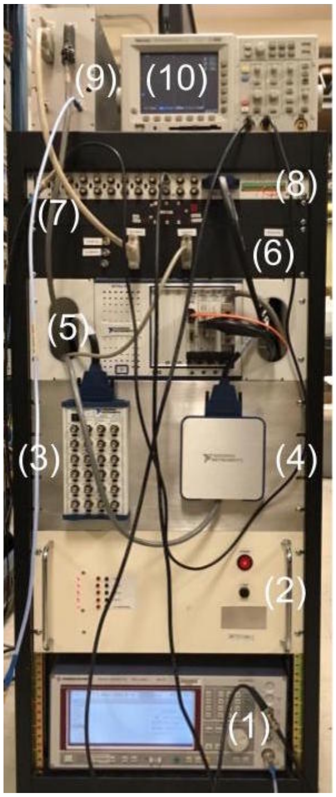

Figure 2.1: NMR rack, front view.

Figure 2.2: NMR rack, back view.

The NMR system is neatly organized in a portable electronics rack as shown in Figures 2.1 and 2.2. The system consists of eleven components: (1) the RF signal generator, (2) the power supply, (3) BNC-2115, (4) SCB-68A, (5) NI PXIe-1071 and modules, (6) the breakout panel, (7) the DIO box, (8) BNC-2090, (9) the "box", (10) the oscilloscope, and (11) the computer. The monitor, keyboard and mouse are on the top of the rack. The following sections detail each of the components.

2.1 Power Supply

The power supply provides power to the Yale card and Q-meter through the box. There are three 25-pin D-subminiature (or D-sub) connectors on the back of the power supply to which power cables can be attached. The device supplies four unique voltages, +24V, +15V, -15V, and +5V. The wiring of the power supply output is covered in Table 2.1.

Pin #	Voltage [V]	Pin #	Voltage [V]
1	+24 RF	14	G
2	+15 RF	15	G
3	+15 LF	16	G
4	-15 LF	17	G
5	+5 S	18	G
6 7 8 9 10 11 12 13	NC	19 20 21 22 23 24 25	NC

Table 2.1: Wiring of output of power supply. NC signifies no connection at the specified pin, and G stands for ground.

The RF (Radio Frequency) and LF (Low Frequency) designations for the voltages in Table 2.1 may seem odd at first, since the power supply is generating DC voltages. These labels actually refer to the op-amp inside the Q-meter which is powered by the specific DC voltage. The "S" label stands for "switching" voltage.

2.2 Breakout Panel

The breakout panel is shown in Figure 2.3. Its purpose is to relocate connections from the back of the Yale card to a convenient place on the front of the NMR rack. It also acts as an intermediary between the computer and the box. It was originally incorporated into the system for convenience, due to the smaller size of our box.

Figure 2.3: Breakout panel.

Input pin #	Connection pin #	Connection Purpose	Connection Type
1	M	Diode	BNC
14	G		
2	NC	N/A	N/A
15	M	DC Monitor	BNC
3	G		
16	NC	N/A	N/A
4	?	Select	25-pin D-Sub REED SWITCH
17	?		
5	?		
18	?	Convert	
6	?		
19	?		
7	24	? Gain	
20	23	? Gain	
8	NC	N/A	N/A
21			
9			
22			
10			
23			
11			
24			
12			
25			
13			

Table 2.2: Breakout panel connection table. For the BNC connectors, M signifies the main, central pin, while G is the gound pin.

The 25-pin D-sub (25D) connector labeled “INPUT FROM BOX” interfaces directly with the box. Connections are made to the two BNC bulkhead connectors labeled “Diode Out” and “DC Monitor”, as well as to the 25D connector labeled “REED SWITCH”. The wiring of the breakout panel is detailed in Table 2.2.

2.3 DIO Box

Figure 2.4: Front panel of the DIO box.

The DIO box, shown in Figure 2.4, acts as an intermediary between the computer and the box. DIO stands for Digital In/Out. The DIO box controls the Select feature, which facilitates switching between Q-meter channels from the computer. These channels are indicated on the DIO box by the six numbered lights. The DIO box also allows the user to select the desired Yale card gain from the computer (see Section 5). The main function of the DIO box is to DC convert the system. The DC convert signal can be sent from the computer, or activated by the button on the DIO box.

Since the portable NMR system covered in this document only uses one Q-meter and Yale card, the Select function of the DIO box is not used. In fact, the DIO box is really not a necessary component of the portable NMR system. However, we included it for similarity to the current setup in Room 28, and to allow for quick and easy DC convert from the rack instead of the computer.

2.4 RF Signal Generator

The RF signal generator used is a Rohde & Schwarz SMT 02 model, which can provide RF signals from 5 kHz to 1.5 GHz. This model is discontinued according to the Rohde & Schwarz website.

The purpose of the RF signal generator is to sweep a frequency range centered on the Larmor frequency of the polarized spins in the target material.

2.5 National Instruments Components

The NMR rack contains four National Instruments components. This hardware functions as a Data AcQuisition (DAQ) device and as an Analog-to-Digital Converter (ADC) for the analog signals. They also facilitate communication and control of the NMR system by the computer.

2.5.1 BNC-2090

The BNC-2090 is a BNC patch panel that collects analog signals from the box and sends them to the NMR ADC.

2.5.2 BNC-2115

The BNC-2115 is another BNC patch panel which accepts analog signals from the "slow control" devices used in conjunction with the NMR system. Such slow control devices include temperature sensors and flow meters, among others, which monitor conditions within the refrigerator during operation. The BNC-2115 passes these analog signals to the DAQ and ADC.

2.5.3 SCB-68A

The SCB-68A box allows the computer to communicate with the DIO box. This allows the user at the computer to adjust the Yale card gain, DC convert the system, and Select the Q-meter channel, right from the computer.

2.5.4 NI PXIe-1071

The PXI system is a platform for PC-computer based measurement and automation systems. The NI PXIe-1071 Express Chassis is a box which manages the PXI system, providing power, cooling, and communication between the PXI modules it houses. Our PXI system uses four modules:

- **NI PXI-6221** This board is part of the NMR DAQ. It functions as the NMR ADC, or Analog-to-Digital Converter.
- **NI PXI-6225** The PXI-6225 board is an Analog Input Multifunction DAQ. It is the "slow control" ADC, converting the analog signals from the slow control devices to digital signals and sending them to the computer. It also acts as an intermediary for computer control of the DIO box.
- **NI PXI-GPIB** This board is a high performance IEEE488 controller module for the PXI system. It enables control of the RF signal generator by the computer.
- **NI PXIe-8375** Through this PXI module, the LabView based computer system can communicate with the PXIe-1071 chassis and modules, and controling the PXI system.

3 The Box

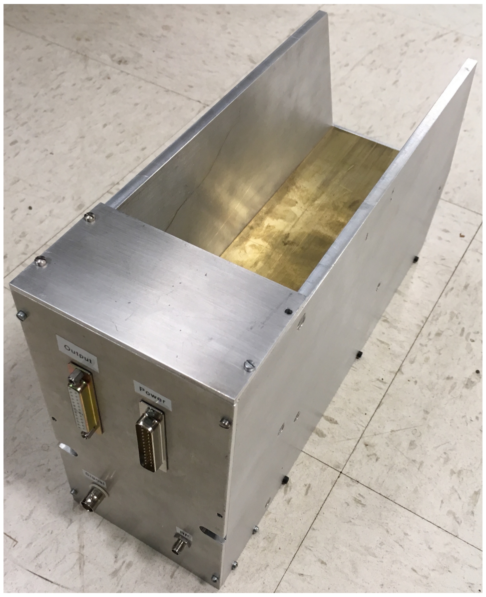

Figure 3.1: Isometric view of the box.

Figure 3.2: Rear view of the box.

The "box", sometimes referred to as "the housing", is the device to which the Q-meter and Yale cards are attached. While it is possible for the Q-meter and Yale card to function without the box, it is nonetheless an essential part of the NMR system.

While modeled after the appearance of the Liverpool box, it is different in many ways. First, it is much smaller, housing only one Q-meter and one Yale card. Also, the Yale card is not housed within the box. The Yale card circuit board is enclosed in a separate housing, which is then connected to the box.

3.1 Box Construction

The box itself consists of nine metal pieces held together by various types of screws. There are three vertical panels, herein referred to as the *front panel*, the *middle panel*, and the *back panel*. These panels are constructed of $\frac{1}{8}$ inch thick aluminum plates. The space between the front and middle panels is the *electronics compartment*, where most of the wiring is housed. The electronics compartment is enclosed on the top and bottom by the *top plate* and *bottom plate*, respectively. The sides of the box are $\frac{1}{4}$ inch thick aluminum plates. The *floor* is a $\frac{3}{8}$ inch thick sheet of brass. The *bottom panel* makes sure the box is mostly enclosed, shielding the internal wiring from any electromagnetic interference.

The front panel has two openings on its face to allow for the installation of a water cooling system. One such opening is labeled (3) in Figure 3.4. The cooling system is currently uninstalled, but will consist of small-diameter copper piping wrapped in a coil attached to the bottom of the floor.

3.2 Box Wiring

This section deals with the internal wiring of the box. Figure 3.3, below, is a rough diagram depicting how the internal wiring of the box is organized. The front, middle and back panels, to which all the wiring is attached, are shown in more detail in Figures 3.4, 3.5, and 3.6, respectively. The following sub-sections give more details on how the wires are connected.

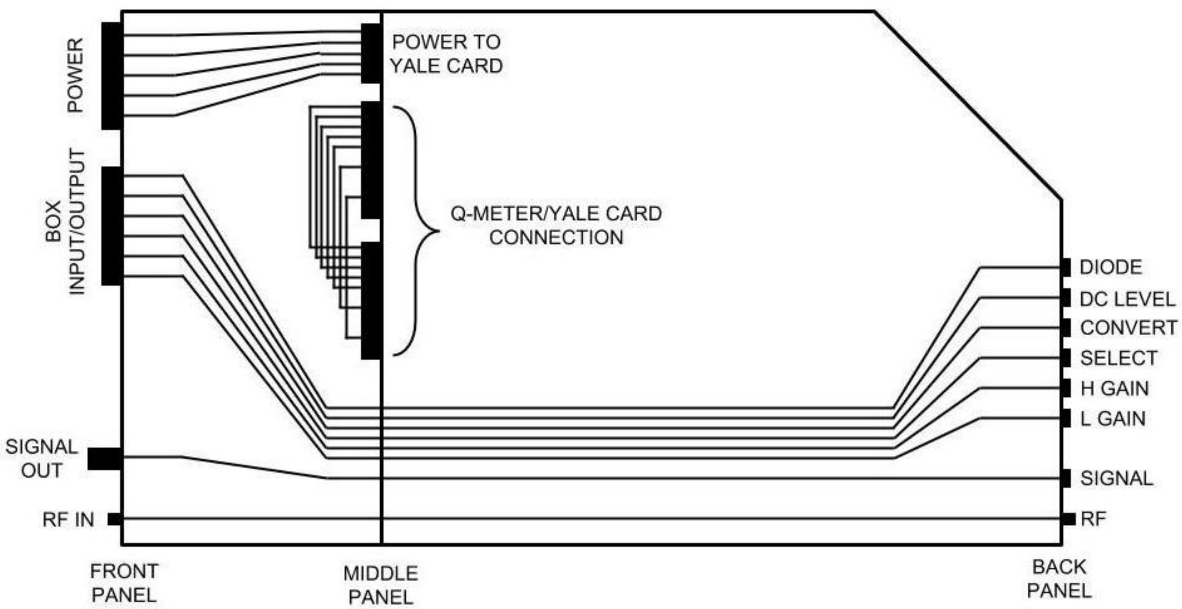

Figure 3.3: Diagram of internal box wiring.

3.2.1 Power

Power is supplied to the box via the male 25D connector on the front panel (number (2) in Figure 3.4). The power input is directly connected to the 15-pin D-sub (15D) connector on the middle panel (number (1) in Figure 3.6), to which the Yale card is connected. There is no direct power connection to the Q-meter. Instead, power is delivered to the Q-meter through the Yale card and the two 25D connectors on the middle panel (numbers (2) and (3) in Figure 3.6, see Section 3.2.4). Table 3.1 shows how power is delivered to the Yale card through the box.

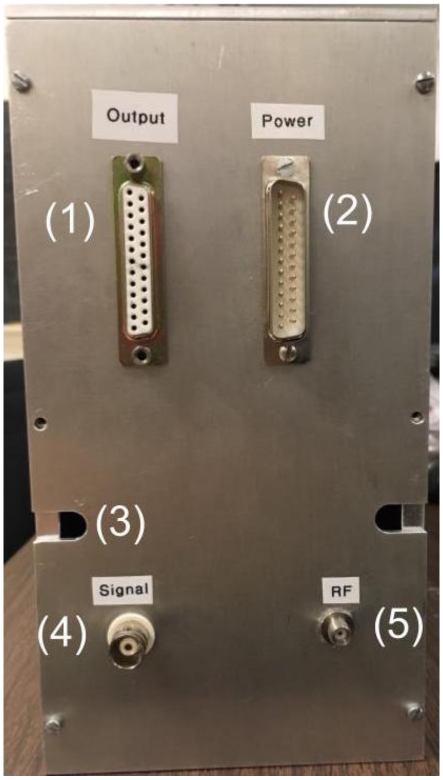

Figure 3.4: Front panel of the box.

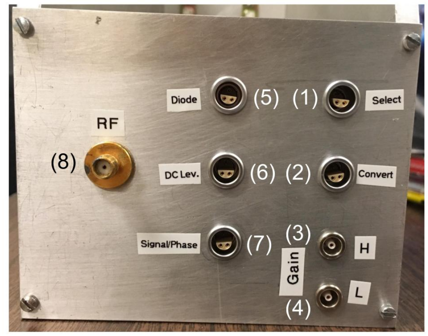

Figure 3.5: Back panel of the box

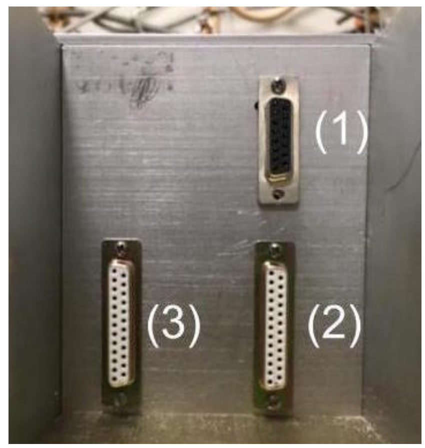

Figure 3.6: Middle panel of the box.

3.2.2 Input and Output

The Input/Output (IO) Interface of the box consolidates connectors (1) - (6) on the back panel (Figure 3.5) into one 25D connector on the front panel (number (1) of Figure 3.4). This includes (1) Select, (2) Convert, (3) High gain, (4) Low gain, (5) Diode, and (6) DC Level/DC Monitor. The box IO then transfers these signals to the breakout panel. The details of the wiring are given in Table 3.2.

The signal/phase line is wired separately to reduce noise (see Section 3.2.3). The RF signal input port, number (5) in Figure 3.4, transfers the RF signal to (8) (Fig. 3.5) on the back panel.

3.2.3 Signal

As mentioned in Section 3.2.2, the phase signal is treated separately from the other box interfaces. The phase signal, or just the signal, is extracted from a

<table>
<tr><th>Power Input Pin #</th><th>15D Pin #</th><th>Voltage</th><th>Power Input Pin #</th><th>15D Pin #</th><th>Voltage</th></tr>
<tr><td>1</td><td>1</td><td>+24 V</td><td>14</td><td>9</td><td>G</td></tr>
<tr><td>2</td><td>2</td><td>+15 V</td><td>15</td><td>10</td><td>G</td></tr>
<tr><td>3</td><td>3</td><td>+ 15 V</td><td>16</td><td>11</td><td>G</td></tr>
<tr><td>4</td><td>4</td><td>-15 V</td><td>17</td><td>12</td><td>G</td></tr>
<tr><td>5</td><td>5</td><td>+5 V</td><td>18</td><td>13</td><td>G</td></tr>
<tr><td>6</td><td rowspan="8">NC</td><td rowspan="8">N/A</td><td>19</td><td rowspan="8">NC</td><td rowspan="8">N/A</td></tr>
<tr><td>7</td><td>20</td></tr>
<tr><td>8</td><td>21</td></tr>
<tr><td>9</td><td>22</td></tr>
<tr><td>10</td><td>23</td></tr>
<tr><td>11</td><td>24</td></tr>
<tr><td>12</td><td>25</td></tr>
<tr><td>13</td><td></td></tr>
</table>

Table 3.1: Box power wiring.

<table>
<tr><th>Port</th><th>LEMO Pin #</th><th>Box IO Pin #</th></tr>
<tr><td rowspan="3">Diode</td><td>1</td><td>1</td></tr>
<tr><td>2</td><td>14</td></tr>
<tr><td>3</td><td>2</td></tr>
<tr><td rowspan="3">DC Level</td><td>1</td><td>15</td></tr>
<tr><td>2</td><td>3</td></tr>
<tr><td>3</td><td>16</td></tr>
<tr><td rowspan="3">Select</td><td>1</td><td>4</td></tr>
<tr><td>2</td><td>17</td></tr>
<tr><td>3</td><td>5</td></tr>
<tr><td rowspan="3">Convert</td><td>1</td><td>18</td></tr>
<tr><td>2</td><td>6</td></tr>
<tr><td>3</td><td>19</td></tr>
<tr><td>H Gain</td><td>1</td><td>7</td></tr>
<tr><td>L Gain</td><td>1</td><td>20</td></tr>
</table>

Table 3.2: Wiring from the back panel to the IO connector on the front panel.

special BNC connector on the front panel (number (4) in Figure 3.4). This is because the signal line must be shielded to reduce noise contamination.

3.2.4 Middle Panel

The middle panel, shown in Figure 3.6, is where the Q-meter and Yale card are connected to the box. The power input on the front panel is connected directly to (1). This 15D connector delivers power to the Yale card. The two

25D connectors (2) and (3) are wired to each other in a one-to-one manner. This connection, detailed in Table 3.3, connects the Q-meter to the Yale card.

(2) - (3) Pin #	Connection
1	C
14	C
2	C
15	C
3	C
16	C
4	C
17	C
5	C
18	C
6	NC
19	NC
7	NC
20	C
8	C
21	NC
9	NC
22	NC
10	NC
23	C
11	C
24	NC
12	NC
25	NC
13	NC

Table 3.3: Wiring between the 25-pin D-sub's (2) and (3) on the middle panel. Since the connections are one-to-one, C signifies a connection, while NC means no connection.

4 The Q-Meter

The Q-meter is a phase sensitive detection device which measures the response of the NMR circuit to the polarization of the target material. It forms the capacitive part of the RLC circuit that comprises the NMR system.[1]

[1] is this fair to say, since other parts of the circuit have capacitance, like the transmission cable?

4.1 NMR & Q-Meter Operation Principles

As mentioned previously, the NMR detection system is basically an RLC circuit. The inductive part of the circuit is a wire loop/coil of bare inductance L_0 in which the target material is placed. The polarized target material has a complex magnetic susceptibility $\chi(\omega) = \chi'(\omega) - i\chi''(\omega)$ which modifies the inductance of the coil to become

$$L = L_0(1 + 4\pi\eta\chi).$$

The constant η is known as the filling factor of the system, and is a measurement of how much target material is inside the coil.

The change in inductance of the coil changes the Q-factor of the circuit. This also results in a change of impedance. By applying a frequency swept RF voltage to the circuit, the change in Q and impedance is measured by the Q-meter as a change in voltage or current.

From this measurement, the (negative of the) imaginary part of the susceptibility is extracted. In a certain approximation, the polarization P of the target material is proportional to the integral

$$P \propto -\int_0^\infty d\omega \, \mathrm{Im}\{\chi(\omega)\}. \tag{1}$$

The constant of proportionality is determined by comparison with the polarization at thermal equilibrium.

4.2 Q-Meter Circuitry

There are two types of Q-meter circuits commonly in use: the constant voltage parallel circuit, and the constant current series circuit, the latter of which is most common and used by the Polarized Target Group. A block diagram of the NMR circuit is shown in Figure 4.1. Everything except the $\lambda/2$ cable, the NMR coil, and the RF source are part of the Q-meter.

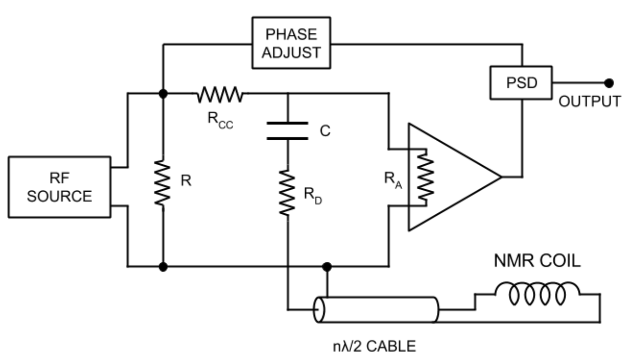

Figure 4.1: Block diagram of the NMR circuit. Modified from Figure 1 of reference [4].

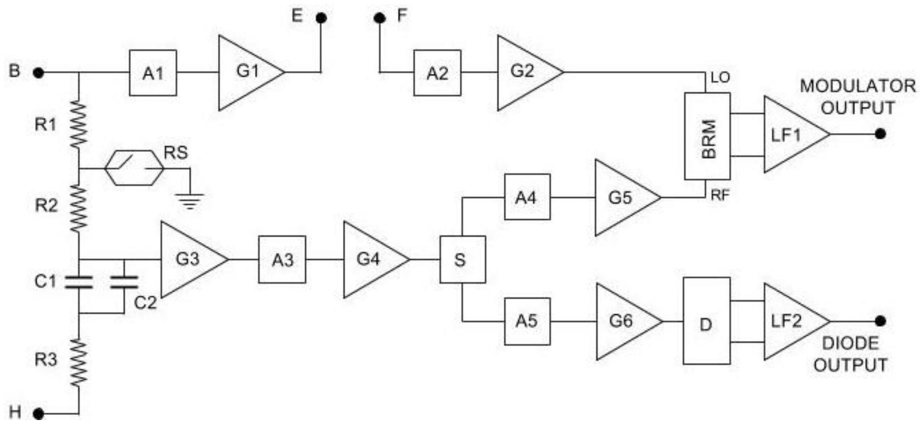

Figure 4.2: Block diagram of the Q-meter's internal circuitry. A1-5 are attenuators. G1-6 are amplifiers. R1 and R2 are the constant-current resistors, and R3 is the damping resistor. C1 and C2 are both tunable capacitors. D is a full wave diode rectifier. BRM is the balanced ring modulator. LF1 and LF2 are both differential amplifiers. S is a two-way splitter and RS is the grounding reed switch. Modified from Figure 7 of reference [3].

Figure 4.2 shows a more detailed block diagram of just the internal Q-meter circuitry. The RF signal generator attaches at socket B, and the $\lambda/2$ cable and coil attaches at socket H. Sockets E and F are connected by an SMA cable, the length of which is adjusted to change the phase of the reference signal.

Equation (1) says that the target polarization P is proportional to the integral of the absorptive part of the complex susceptibility, χ''. Thus, the output of the Q-meter needs to be relatable to χ''. Some Q-meter circuits can detect only $|\chi(\omega)|$. This is a disadvantage because extracting χ'' from $|\chi(\omega)|$ requires a tedious correction to account for the dispersive part of the susceptibility, χ', which also introduces uncertainty into the measurement. The Liverpool Q-meters used by the Polarized Target Group measure only the absorption by use of a balanced ring modulator (BRM).

The output of the BRM is proportional to the real part of the input signal.

This method is called phase sensitive detection because either the real or imaginary parts of the NMR signal can be selected by comparison with the phase of a reference signal.

If the phase difference between the LO and RF BRM input signals is zero, then the real part of BRM output is proportional to the real part of the NMR signal, which is in turn proportional to the imaginary part of the complex susceptibility.

4.3 Q-Meter Housing

The circuitry just discussed is housed within a rectangular box, which is called a Q-meter. The front of the Q-meter housing, shown in Figure 4.3, has one 25D connector which accommodates the power supply input and detected outputs. The top of the housing, Figure 4.4, has two SMA sockets labeled (1) and (2). The knob (3) is a fine adjustment knob for the tuning capacitor. The back of the Q-meter is shown in Figure 4.5. An RF signal is delivered to the Q-meter through socket (1). The inductive coil is attached at socket (4). The small hole (3) is an access port which allows for coarse adjustment of the internal tuning capacitor.[2] The light (2) is an indicator light. When used in conjunction with other Q-meters, the light will be lit if the Q-meter channel is inactive **check this**.

Figure 4.3: Front of the Q-meter.

Figure 4.4: Top of the Q-meter.

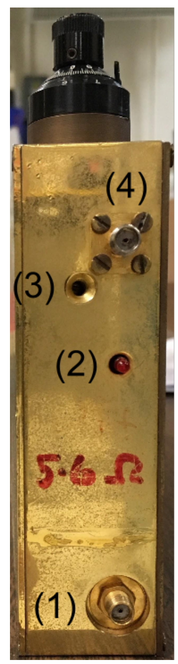

Figure 4.5: Back of the Q-meter.

A PDF can be found on the UVA Polarized Target Group website detailing the internal circuitry of the Q-meter[3].

[2]Insert a small flat-head screwdriver into the access port to adjust the capacitor.

5 The Yale Card

The Yale card is a circuit board used for signal amplification and DC voltage compensation. Although not an essential component of a Q-meter based NMR system, it plays an important role in our NMR system.

5.1 Yale Card Housing

In some NMR systems, such as the Liverpool system in B28, the Yale card circuit board is incorporated into the Box. However, the portable NMR system uses a Yale card that is external to the Box; enclosed in its own housing.

Figure 5.1: Front of the Yale card housing.

Figure 5.2: Back of the Yale card housing.

The front of the Yale card housing is shown in Figure 5.1. Power is delivered to the internal circuit board through the 15D connector (1). The 25D connector (2) connects to the Q-meter in a one-to-one manner detailed in Table 3.3.

The back of the Yale card housing, shown in Figure 5.2, holds all the interface ports. There are five 3-pin LEMO connectors for Diode, Select, Signal, DC Level/DC Monitor, and Convert. The two single-pin LEMO sockets and corresponding switches control the gain settings of the Yale card.

The Yale card has three possible gain settings (1, 20, and 50) which can be controlled manually by the switches, or electronically through the LEMO sockets. When both switches are down, there is no gain. Activating the low gain switch gives a gain of 20. Activating both switches gives a gain of 50. Activating the high gain switch alone does nothing. It is also possible to control the Yale card gain through the LEMO connectors. **more**

5.2 Yale Card Housing Wiring

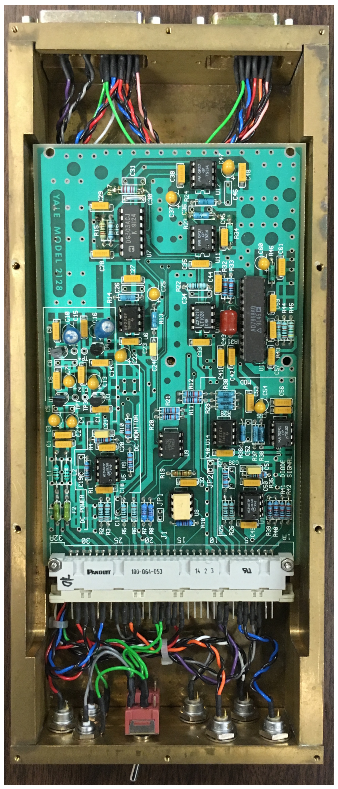

Figure 5.3: Internal view of the Yale card housing and circuit board.

Figure 5.4: Internal wiring of the Yale Card housing.

The internal wiring of the Yale card housing is shown in Figure 5.4. The Yale card circuit board is plugged into the 32-pin DIN connector, which is wired to the 3-pin LEMO sockets and the 25D connector according to Table 5.1. The 25D connector is also wired to the 15D power supply connector. Some of these connections are doubled up on a single pin. The details of this connection, from the perspective of the 25D connector, are shown in Table 5.2.

YC Pin #	Connection Pin #	Connection Name	Wire Color
1 2	NC	N/A	N/A
3	25D20	?	black
4	25D8	?	gray
5	3L?	Diode	black
6	3L?		blue
7	NC	N/A	N/A
8	25D23	?	black
9	25D11	?	purple
10 11 12 13 14	NC	N/A	N/A
15	3L?	Convert	black
16	3L?		red
17	?	Reed Switch?	black
18	?	H Gain switch	green
19	?	L Gain switch	green
20 21	NC	N/A	N/A
22	3L?	Phase/Signal	black
23	3L?		orange
24	3L?	DC Monitor/Level	black
25	3L?		gray
26	NC	N/A	N/A
27	25D4	?	blue
28	NC	N/A	N/A
29	25D17	?	black
30	25D16	?	black
31	25D3	?	red
32	NC	N/A	N/A

Table 5.1: Internal wiring of Yale card Liverpool housing. The notation 3LX refers to pin X of a 3-pin LEMO connector.

6 Connecting the NMR System

This section will describe how all the components of the NMR rack discussed in the previous sections are connected. A diagram depicting the connections between major components of the NMR rack is given in Figure 6.1. The diagram includes all the National Instruments components and the DIO box.

Pin #	Connection Pin #	Wire Color
25D1	15D1	pink
25D2	15D2	orange
25D3	15D3, YC31	red
25D4	15D4, YC27	blue
25D5	15D5, RR ??	
25D6	NC	N/A
25D7	NC	N/A
25D8	YC4	gray
25D9	NC	N/A
25D10	NC	N/A
25D11	YC9	
25D12	NC	N/A
25D13	NC	N/A
25D14	15D9	black
25D15	15D10	black
25D16	15D11, YC30	black
25D17	15D12, YC29	black
25D18	RR ??	white
25D19	NC	N/A
25D20	YC3	black
25D21	NC	N/A
25D22	NC	N/A
25D23	YC8	black
25D24	NC	N/A
25D25	NC	N/A

Table 5.2: Wiring of the Yale card 25D connector.

6.1 Connections

The NI PXIe-1071 chassis forms the backbone of the NMR rack; all components of the NMR rack are connected to one of the four modules, either directly or indirectly. The NI PXI-GPIB board is connected to the RF signal generator by a 10833A GPIB cable. The NI PXI-6221 card is connected to the BNC-2090 panel by a SHC68-68-EPM cable. The NI PXI-6225 has two ports. "CONNECTOR 0 (AI 0-15)" is connected by a SHC68-68 cable to the SCB-68A box, and "CONNECTOR 1 (AI 16-79)" is connected by a SHC68-68-EPM cable to the BNC-2115 panel. The NI PXIe-8375 board also has two ports. The top port, labeled "(UPSTREAM) PORT 1", is connected to a PCIe card on the computer by a ZL60615 optical cable. The bottom port, "(DOWNSTREAM) PORT 2" is not connected to anything.

Using a BNC T-connector, connect both the signal line and oscilloscope channel 2 to the "ACH1" port on the BNC-2090 patch panel. On the spring connection block, make connections between PFI (Programmable Function Input channels) port 2 and 9, and between PFI port 5 and "CTR0OUT" (Counter 0 Out). Using another BNC T-connector, connect "DAC0OUT" (Digital/Analog Converter 0 Out) on the BNC-2090 and oscilloscope channel 1 to the "EXT 1" port on the RF signal generator.

6.2 SCB-68A Wiring

As mentioned in the previous section, the SCB-68A box is connected to the PXI-6225 card of the PXIe-1071 chassis. It is also connected to the "DIO" port on the back of the DIO box by a custom 25D cable.

The interior of the SCB-68A box houses four screw terminals (J4, J5, J6, and J8), and two switch boxes (S1 and S2). The temperature sensor switches S1 and S2 should be in the factory default "Disabled" mode, as depicted on the inside panel of the magnetic cover. Wiring connections will only be made on the middle two screw terminals, J4 and J8. The details of the connections are specified in Table 6.1.

<table>
<tr><th>SCB-68A J8 Pin #</th><th>Cable Pin #</th><th>SCB-68A J4 Pin #</th><th>Cable Pin #</th></tr>
<tr><td>59</td><td rowspan="12">NC</td><td>51</td><td>25D6</td></tr>
<tr><td>25</td><td>17</td><td>25D2</td></tr>
<tr><td>58</td><td>50</td><td>NC</td></tr>
<tr><td>24</td><td>16</td><td>25D14</td></tr>
<tr><td>57</td><td>49</td><td>25D3</td></tr>
<tr><td>23</td><td>15</td><td>NC</td></tr>
<tr><td>56</td><td>48</td><td>25D15</td></tr>
<tr><td>22</td><td>14</td><td>NC</td></tr>
<tr><td>55</td><td>47</td><td>25D4</td></tr>
<tr><td>21</td><td>13</td><td rowspan="4">NC</td></tr>
<tr><td>54</td><td>46</td></tr>
<tr><td>20</td><td>12</td></tr>
<tr><td>53</td><td>25D17</td><td>45</td></tr>
<tr><td>19</td><td>25D5</td><td>11</td><td>25D16</td></tr>
<tr><td>52</td><td>25D1</td><td>44</td><td rowspan="2">NC</td></tr>
<tr><td>18</td><td>NC</td><td>10</td></tr>
</table>

Table 6.1: Connections from SCB-68A to the DIO box. The notation 25DX refers to pin X of a 25-pin D-sub connector.

6.3 BNC-2115 Connections

As mentioned previously in Section 2.5.2, the BNC-2115 is a patch panel for the slow control ADC. All slow control monitoring devices are connected to this panel. Each BNC port has two connection settings, Floating Source (FS) or Ground-referenced Source (GS), which can be toggled by a switch under the connector.

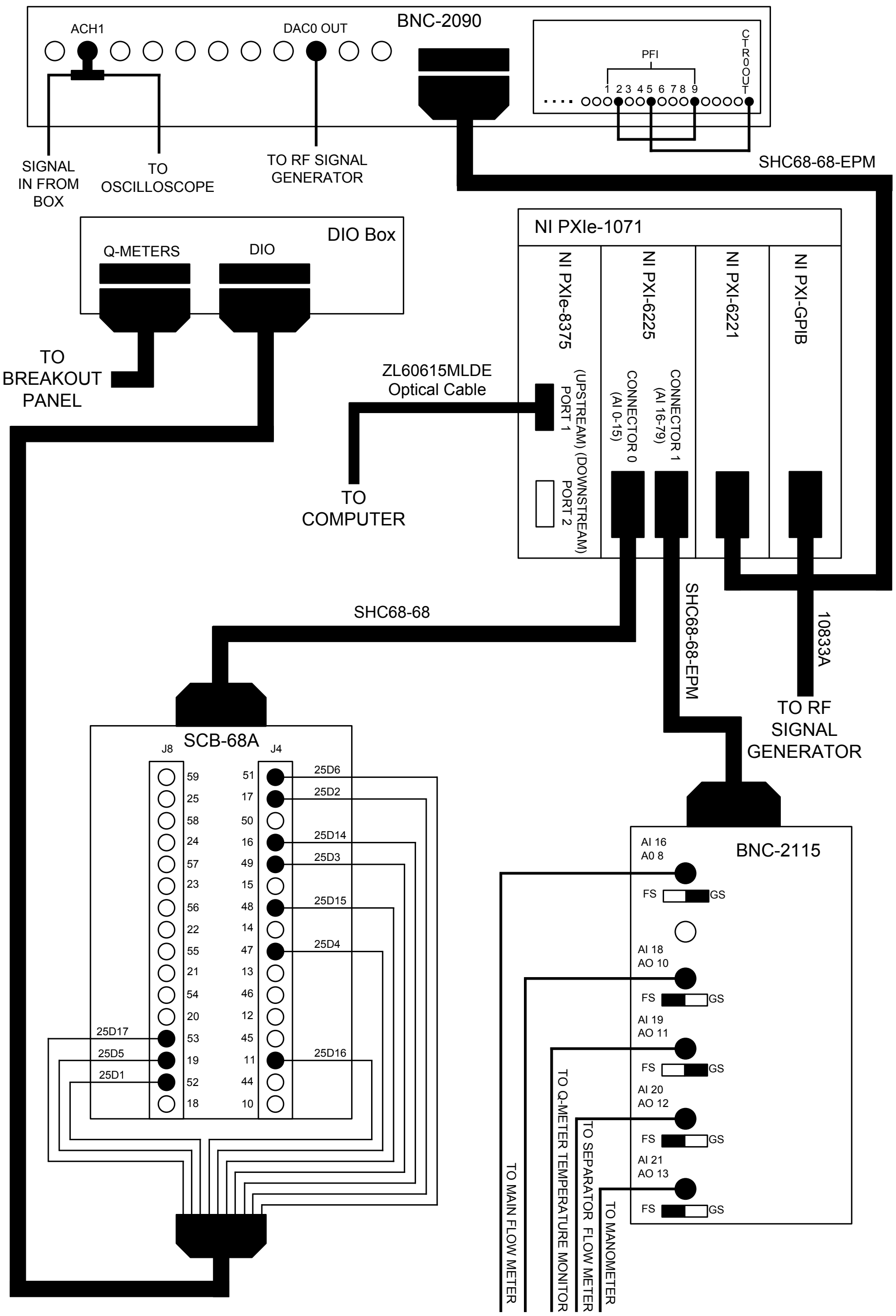

Figure 6.1: NMR rack component connection diagram.

BNC-2115 Port #	Slow Control	Source
AI 16/AO 8	Main Flowmeter	GS
AI 17/AO 9	NC	N/A
AI 18/AO 10	UNKNOWN	FS
AI 19/AO 11	Q-Meter Temp. Monitor	GS
AI 20/AO 12	Sep. Flow Meter	FS
AI 21/AO 13	Manometer	FS
$\vdots$	NC	N/A

Table 6.2: BNC-2115 slow control ADC connections.

6.4 Connecting the Box

To begin, slide the Q-meter and Yale card housing into the appropriate ports on the box's middle panel. Once attached to the box, the Yale card and Q-meter interfaces must be connected to the back panel.

There are only two connections for the Q-meter. Using a short SMA cable, attach the RF out port (8) (Fig. 3.5) to port (1) (Fig. 4.5) on the Q-meter. Then, connect the $\lambda/2$ cable to port (4) (Fig. 4.5) on the Q-meter.

The Yale card interfaces must be connected to the box by 3-pin LEMO cables. For basic functionality, there are only three necessary connections: Diode, Convert, and Signal, as shown in Figure 6.2. In our current setup, we take the signal directly from the Yale card, bypassing the box. As of yet, we are unable to control the gain switches from the computer (**WHY?**).

The Q-meter must also be connected to the box to receive the sweeping RF signal from the RF signal generator. Using a short SMA cable, connect the RF port on the back panel of the box to port (1) (Fig. 4.5) on the Q-meter.

7 The PDP System

The Polarization Display Panel, or PDP for short, is the name of the LabView based software developed by the Polarized Target Group for use with the NMR systems. While the software is powerful in many respects, It is an outdated system in the sense that changes have been made in the NMR setup that have not been reflected in the PDP program.

From the computer desktop, the PDP software can be opened by double-clicking on the icon “TPS System Start”. Once started, nine windows will open. The windows are “Magnet Control”, “Temperature”, “NMR Program”, “Event Builder”, “Microwave”, “Logger”, “Analysis”, “TPS System Start.vi Front Panel”, and “Display”. The “Display” window is the main window of the program, the graphical user interface (GUI).

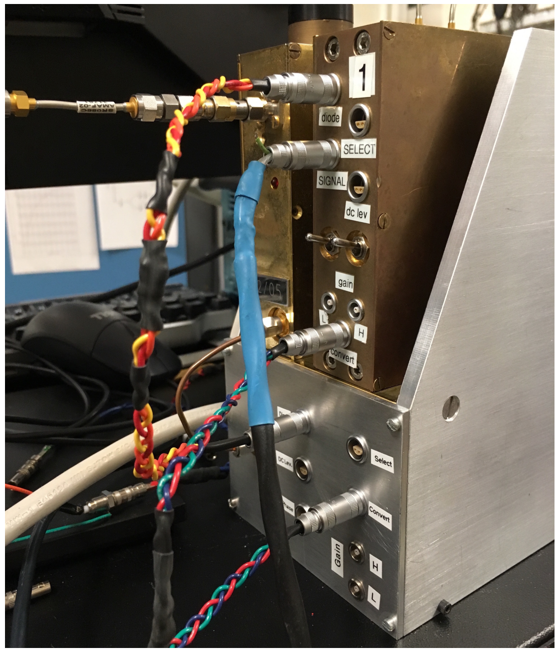

Figure 6.2: Connecting the Yale card to the box.

7.1 PDP "Display" GUI

Ideally, the entire NMR system can be controlled and monitored from the PDP GUI, shown in Figure 7.1. The display window is divided into 10 sections, each controlling or monitoring a certain part of the system. Since this document is focused on acquiring a working knowledge of the portable NMR system, only the most important parts of the PDP GUI will be discussed here.

The NMR system is controlled from section (1). A detailed view is shown in Figure 7.2. The section contains six distinct areas, labeled (1a) through (1f).

Section (1a) contains three buttons. There functionality is described in the following list.

- **Init QCA** ???
- **Save Chan List** ???
- **Stop NMR Sweep** ???

Section (1b) is the "NMR Channel" list. This menu allows the user to select a specific spin species, which populates the settings in sections (1d) and (1e) with specific preset values. The "Top" and "Bottom" designations for some of the options specify the cup location, assuming the target stick has only two cups for target material. The options in this menu are largely ignored, and the

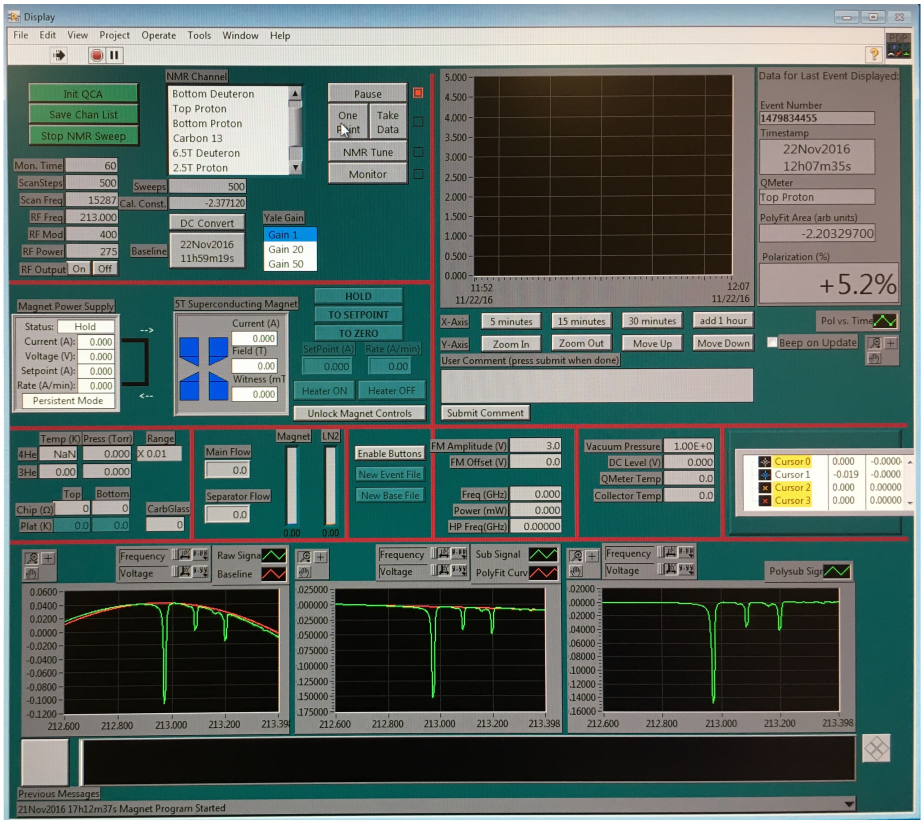

Figure 7.1: The PDP Display GUI.

values in sections (1d) and (1e) are entered by hand.

The five buttons of Section (1c) control the NMR system.

- **Pause** Pauses the current operation. **more**
- **One Point** Click this button to take one data point. For use when taking a baseline measurement. **MORE**
- **Take Data** Normal data taking mode. The system will continuously perform sweeps of the frequency, and return the target polarization as a function of time. **???**
- **NMR Tune** Click this button to start the system for tuning. See Section 8 for details on the tuning procedure.
- **Monitor** **???**

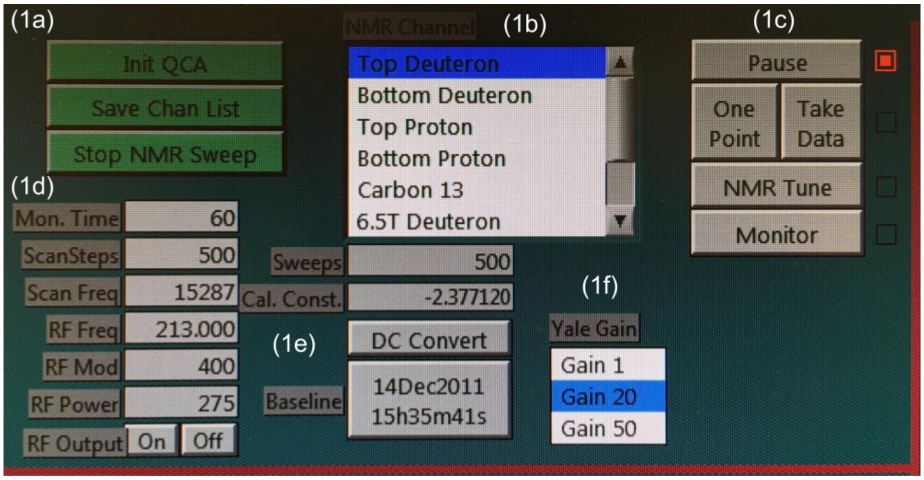

Figure 7.2: Section (1) of the PDP GUI.

Section (1d) controls the output of the RF signal generator. The preset values shown correspond to the choice of spin species selected from the menu in section (1b).

- **Mon. Time** ???
- **ScanSteps** ???
- **Scan Freq** ???
- **RF Freq** This field is for the Larmor frequency of the spin species under consideration. The intrinsic units are MHz. The RF signal generator sweeps through this frequency... **more... ???**
- **RF Mod** ???
- **RF Power** ???
- **RF Output** The two buttons "On" and "Off" either initiates or halts output from the RF signal generator.

Section (1e) ... **more**

- **Sweeps** ???
- **Cal. Const.** This field contains the calibration constant that relates the integral of the pure NMR signal to the target polarization.
- **DC Convert** Click this button to remove any accumulated DC offset from the signal. This function is also available from the DIO box.

- **Baseline** Click this button to either create a new baseline, or select an existing baseline. The button displays the date and time that the current baseline was created.

Section (1f) controls the gain of the Yale card. As of the writing of this document, the Yale card gain cannot be selected from the PDP program.

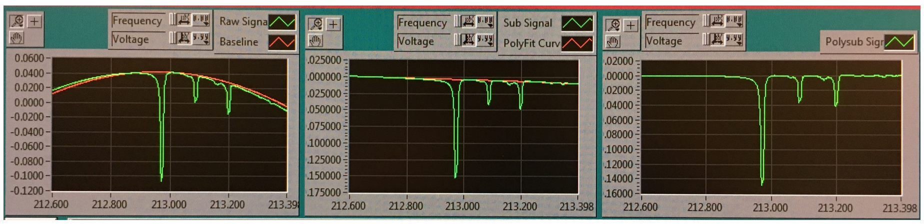

Figure 7.3: Closeup of Section (2) of the PDP GUI.

The three plots of section (2) display the NMR signal (voltage) from the Q-meter as a function of frequency. The left plot displays the raw NMR signal (green) and the “baseline” or “Q-curve” from the Q-meter (red). The middle plot shows the “sub-signal”, which is the raw NMR signal with the baseline subtracted from it. The “PolyFit Curv” (red) is a polynomial fit to any residual noise on the signal. **???** The right-most plot shows the pure NMR signal (Polysub Sig) with all background subtracted.

Section (3) is the polarization display panel. The plot here shows the polarization of the target as a function of time. The target polarization is linearly related to the integral of the pure NMR signal by the calibration constant.

$$\left(\int_0^\infty d\nu \, \mathrm{PolysubSig}(\nu) \right) C = P$$

8 Tuning the NMR

Tuning the NMR is the process of adjusting the system to obtain a strong signal from the target, with as little noise as possible.

This section details the steps in the tuning procedure. For a brief tuning guideline, see the document on the UVA Polarized Target Group website[2]. Before attempting to tune the system, make sure that all components are properly connected (see Section 6).

8.1 Initial Startup

This section details the essential steps to starting up the system from a complete shutdown.

- **Power On Equipment.** Plug in the main power cable to provide power to the NMR rack. Then, turn on the RF signal generator, the power supply, the PXIe-1071, the oscilloscope, and the computer.
- **Run Systems Check (Optional).** This optional step is to ensure that all the NI components are properly connected, and being read by the LabView software. Open the "Measurement & Automation Explorer" program. Under the "My System" tab, click on the "Devices and Interfaces" tab. A list of all NI components will appear. If an error occurs, a red circle with a white "x" will appear on the device icon. The suggested fix is to restart the whole system (See Appendix A for more troubleshooting options).
- **Run PDP Software.** Once the PDP program has started, nine windows will open. In the "Temperature" window, de-select "Read He4 Manometer" and "Read LakeShore", and then minimize the window. In the "Microwave" window, de-select "Read EIP", and minimize this window also. Minimize all remaining windows except the "Display", as this is the main window.

Once the NMR system is up and running, one can start the tuning procedure.

8.2 Tuning Procedure

As a preliminary step, make sure that the oscilloscope settings are properly configured. That is, it should be in " x vs. y" mode, channel 1 should be set to DC mode, and the ground level should be adjusted to zero. In the PDP GUI, choose the appropriate "NMR Channel", or enter the appropriate Larmor frequency, and then click "NMR Tune" to begin the tuning procedure.

1. **Connect Oscilloscope to "Diode Out".**
   Connect oscilloscope channel 2 to the "Diode Out" port on the breakout panel, and put it on DC mode. Check the Diode voltage on the scope to make sure it is less than 3V. If the DC Diode voltage is greater than 3V, move on to step (2). If the voltage is less than 3V, ideally less than 1V, move on to step (3).
2. **Adjust $\lambda/2$ Cable.**
   If the DC Diode voltage reads above 3V, adjust the length of the $\lambda/2$ cable until the signal is less than 3V, ideally less than 1V. See Appendix B on calculating $\lambda/2$.
3. **Fine Tune Q-meter Capacitor.**
   While still connected to "Diode Out", switch oscilloscope channel 2 to AC mode, adjusting the scale knobs as necessary. If the signal is uneven, as in Figure 8.2, use a small screwdriver to fine tune the Q-meter's capacitor until the signal on the oscilloscope is as symmetric as possible, as shown in Figure 8.3. [3]

[3] Make sure the signal has the correct concavity. The signal should be concave-up on diode;

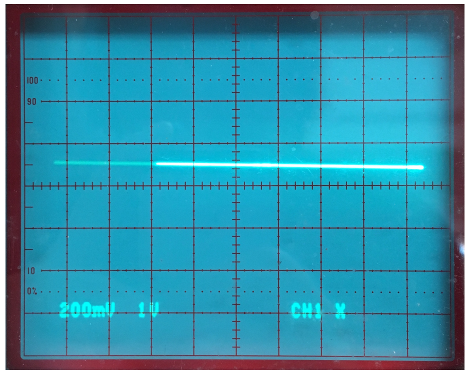

Figure 8.1: Oscilloscope image of the diode voltage, less than 1V.

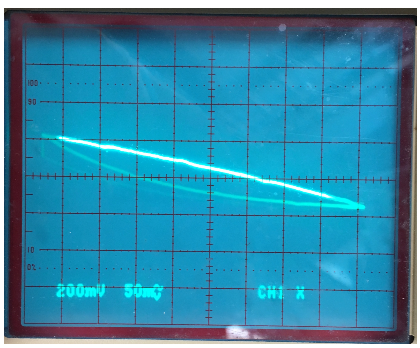

Figure 8.2: Oscilloscope AC Diode signal before adjusting Q-meter capacitor.

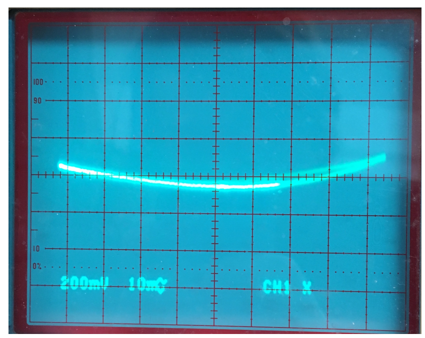

Figure 8.3: Oscilloscope AC Diode signal after adjusting Q-meter capacitor.

4. **Connect Oscilloscope to Signal.**
   Connect oscilloscope channel 2 to the phase signal (through the BNC T-connector attached to ACH1 on the BNC-2090 panel), and switch it back to DC mode.

5. **Adjust Phase Cable.**
   Adjust the length of the phase cable to make sure the signal is symmetric. Add or remove length to the phase cable based on the following principle: "High on the **R**ight, **R**emove. High on the **L**eft, **L**engthen."

6. **DC Convert.**
   Press the DC convert button to remove any built-up DC offset voltage. Do this every time the phase cable is adjusted. Also, make sure that the ground level for oscilloscope channel 2 is still at the zero level.

---

concave-down on phase.

7. **Test System With Crystal.**
   The final step is to test the system using a special crystal oscillator. Select a crystal with resonant frequency equal to (or close to) the Larmor frequency to be swept by the RF signal generator. When the wire loop attached to the crystal is moved near the coil, a signal can be observed on the oscilloscope. If all is satisfactory, then the tuning procedure is complete.

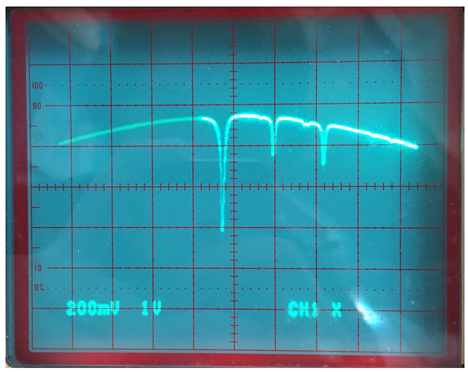

Figure 8.4: NMR signal from a test crystal.

For certain spin species, tuning the NMR may require a $\lambda/2$ cable in excess of five meters. This often makes tuning the diode a difficult task since the tolerance for errors in the length of the cable are greatly reduced.

Also, the diode signal on the oscilloscope may appear different than that corresponding to a different spin species with shorter $\lambda/2$. The signal may appear flat with a kink. To tune the diode, one must either add or remove cable so that the kink is shifted and the signal is symmetric. The diode voltage may also appear parabolic, instead of linear.

A Troubleshooting

Sometimes things don't run as usual during operation of the NMR system. This appendix covers some of the most common problems encountered during operation, and some suggested fixes.

A.1 No Signal on Oscilloscope

Sometimes during operation, the signal may disappear from the scope, leaving just a central bright spot on the screen.

- Check the connections on BNC-2090. Sometimes the wires on the spring connection block can become loose, causing the signal to disappear. Fiddle around with the connection until the signal is restored.

A.2 Unexpected Signal on Oscilloscope

- Make sure the system is far away from any magnetic fields. Strong magnetic fields can effect the internal operation of the Q-meter, causing any signal to disappear from any tuned NMR system.

A.3 Unchanging Diode Voltage

Sometimes when adjusting the $\lambda/2$ cable, the diode voltage remains at a high level, the intrinsic diode voltage of the Q-meter (around 7 to 15 V).

- There could be a bad connection in the $\lambda/2$ cable. Make sure all SMA connections are tight.
- This could also be caused by a bad SMA cable itself. Try replacing some cables to try and isolate the defective cable.
- Maybe the "$\lambda/2$" cable length is nowhere close to the correct length. For some spin species, the external cable length L (see Appendix B) can be meters long (even with $n = 1$). In this case, the tolerance for error in L is very low.

A.4 Noisy Signal

If the signal is more noisy than usual, ... **more**

- Check the connections on the $\lambda/2$ cable. If the cable is made of many segments, the connections can become loose if the cable is moved around. Make sure all SMA connections are tight.
- Check the jumper connections on the BNC-2090 patch panel. If these wires become loose, it can contribute to a noisy signal.

B Calculating $\lambda/2$

Calculating the length of the $\lambda/2$ cable is a crucial step during the tuning process. For the NMR system to be properly tuned and in phase, the tuning capacitor and the NMR coil must be connected by a cable of length $\lambda/2$, or an integer multiple of $\lambda/2$. However, since our experimental setup includes the Q-meter and target stick, what we call the "$\lambda/2$" cable is not actually this long. The tuning capacitor is internal to the Q-meter housing, so there is a short length of cable ℓ_Q that is internal to the Q-meter. The NMR coil resides within the cup at the end of the target stick. A SMA cable of length ℓ_S, "internal" to the stick, connects the coil to a bulkhead socket on the top of the stick. So, in reality, we connect socket (4) (Fig. 4.5) on the Q-meter to the appropriate port on the top of the target stick by a cable of length L, which we call the "$\lambda/2$" cable for convenience. Thus, we get the following relationship.

$$\frac{n\lambda}{2} = L + \ell_Q + \ell_S \tag{2}$$

Whats left is to calculate the wavelength for the given spin species. For electromagnetic waves, the frequency f, propagation speed v, and wavelength λ are all related by the simple kinematic equation

$$\lambda = v\frac{1}{f}.$$

The speed of propagation v in a dielectric medium (the SMA cable) is some fraction β of the speed of light in vacuum, c. That is, $v = \beta c$. The fraction β is determined by the electrical and magnetic properties of the SMA cables through which the signal propagates. Assuming that the coaxial insulation is non-magnetic, $\mu \approx 1$, we have

$$\beta = \frac{1}{\sqrt{\epsilon\mu}} \approx \frac{1}{\sqrt{\epsilon}}.$$

In an external magnetic field B, the magnetic moment of a particle/system will precess about the field lines at a frequency

$$f = \frac{|\gamma|}{2\pi}B \tag{3}$$

known as the Larmor frequency. Combining the results and dividing by two gives an expression for half the wavelength

$$\frac{\lambda}{2} = \left(\frac{\beta}{2}\right)\frac{c}{f}$$

Solving equation (2) for L and substituting the above result gives an expression for the length of the external portion of the $\lambda/2$ cable.

$$L = n\left(\frac{\beta}{2}\right)\frac{c}{f} - \ell_S - \ell_Q \tag{4}$$

The value of n chosen is dictated by the experimental setup; L must be long enough to reach the stick from the NMR rack.

References

[1] Ryan Duve, Yale Card Housing Installation.

[2] Nadia Fomin, Everything you've ever wanted to know about tuning the NMR, but were afraid to ask.

[3] Liverpool NMR Module, Q-Meter Fundamentals, and Circuit Testing.

[4] G Court, et al., Nucl. Instr. and Meth. A 324 (1993) 433.

[5] D Keller, Nucl. Instr. and Meth. A 728 (2013) 133.