PMT Base Capacitors and Resistors at Nitrogen Temperatures and Operating Voltages

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1. Introduction

When conducting experiments in extreme conditions, it is imperative that the components used can be trusted to work as expected. To avoid failure, tests need to be performed to ensure their functionality isn't compromised by the operating conditions of the experiment.

In MicroBooNE and Dark Matter experiments, certain capacitors and resistors will be employed in PMT bases at liquid argon temperatures (-186 °C or about 87 K). These components were assessed for their ability to maintain their desired capacitances and resistances at liquid nitrogen temperature and operating voltages. Liquid nitrogen was chosen because of its commercial availability with an added bonus of being colder than liquid argon (-196 °C or about 77K). The capacitors being tested were two values, both from Digi-Key Corporation: 8.2 nF and 22 nF capacitors (see Figure 1). All resistors were purchased from Digi-Key except for the 500 MΩ OhmCraft resistors and had resistances that ranged from 51 Ω to 500 MΩ (see Figure 2). COG/NPO capacitors and metal film resistors were selected because they were believed not to be affected by temperature. However, the 500 MΩ resistor was not available in metal file so we might expect it to change its resistances with temperature.

Capacitors and Resistors: [1]

8.2 nF ceramic COG/NPO, voltage rating: 1000 V, P/N: 478-3022-6-ND

22 nF ceramic COG/NPO, voltage rating: 250 V, P/N: 445-2357-1-ND

51 Ω, 1/8 watt, 0805 metal film, P/N: P51DACT-ND

150 k Ω, 1/4 watt, 1210 metal film, P/N: P150KQCT-ND

200 k Ω, 1/4 watt, 1210 metal film, P/N: P200KQCT-ND

*270 k Ω, 1/8 watt, 0805 metal film, P/N: P270KDADKR-ND

*470 k Ω, 1/4 watt, 1206 metal film, P/N: RHM620KAICT-ND

*560 k Ω, 1/8 watt, 0805 metal film, P/N: P560KDADKR-ND

*620 k Ω, 1/4 watt, 1210 metal film, P/N: P68KQCT-ND

**500 MΩ, non-metal film, special HV, P/N: HVC1206K5006JB (OhmCraft)

If these capacitors and resistors are not damaged or changed by the conditions of the test, they can be safely used in Microboone and Dark Matter experiments knowing they will operate as needed.

[1] * Resistors used in Dark Matter experiments, not MicroBooNE
** Resistors used in Dark Matter experiments and MicroBooNE

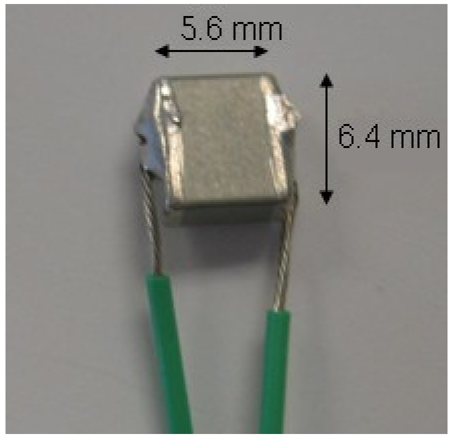

Figure 1: 8.2 nF capacitor

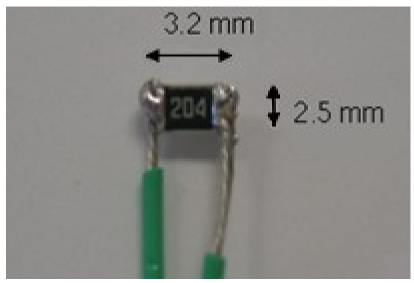

Figure 2a: 200 kΩ resistor

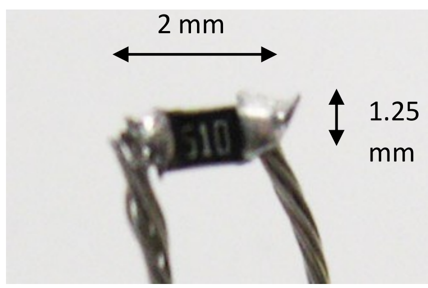

Figure 2b: 51 Ω resistor

2. Methods and Materials

i. Testing Capacitance

To test the capacitances, we used a Sencore Capacitor-Inductor Analyzer Model LC76 (see figure 3). This test was done at room and liquid nitrogen temperatures, the room temperature data acting as a baseline to monitor whether the cold temperature affected the electronics. Before testing the capacitors, wire leads were soldered to the ends which allowed the capacitors to remain completely immersed in the liquid while still connected to the Analyzer.

Once the probes were attached and the capacitors were in the nitrogen, cooled such that the liquid around the capacitors no longer boiled, the capacitances were measured (see Figure 4). The capacitors were then removed from the nitrogen and warmed back up room temperature, after which they were placed in the nitrogen again and their capacitances were measured. The purpose of cycling between room and liquid nitrogen temperatures was to determine if the temperature shocks impacted the capacitor’s performance.

This process was done five times per capacitor.

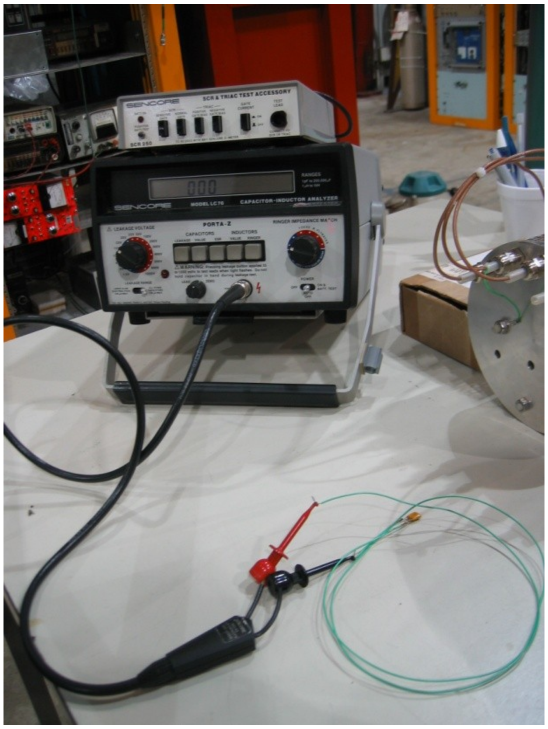

Figure 3: Sencore Capacitor-Inductor Analyzer

Figure 4: Nitrogen pot in which the capacitors were placed

ii. Testing Voltage across Capacitors

In order to ensure the capacitors did not leak current at operating voltages, a high voltage supply was used to test them. If a capacitor could not tolerate the voltage, it would draw a current which the supply would register.

The supply was connected to each capacitor, and the voltage was slowly increased until across the capacitor there was twice as much voltage as the stand-off voltage given by the manufacturer. At that point, the current was measured using the supply. This was performed at room and liquid nitrogen temperatures with wire leads soldered to the ends of the capacitors.

iii. Testing Resistance

Wire leads were soldered to the ends of the resistors, allowing them to remain in the nitrogen while the measurements were taken. For the resistors, a Hewlett Packard 3457A multimeter was used to measure resistance (see Figure 5). Each resistor was connected to the multimeter, and its resistance measured, at room temperature and again in liquid nitrogen.

Figure 5: Hewlett Packard multimeter

iv. Testing Voltage across Resistors

The resistors were connected to the high voltage supply, and the voltage across the resistors was measured at four different currents. These values were chosen specifically because of the PMT base designs (see Figure 6). Given that the maximum voltage across the MicroBooNE base is 2000 V and the total resistance is 4052 kΩ, 0.5 mA is the maximum current passing through any resistor. As such, we tested to the maximum current the supply could provide, about 0.8 mA, and took readings. Rather than reading the voltages using the high voltage supply, a Fluke multimeter was used to measure the voltage directly across the resistors. The high voltage supply had an internal 200 kΩ resistor in series with our resistors, and the Fluke multimeter allowed us to ignore this resistor in our data analysis. The current readings were given by the high voltage supply.

This procedure was performed at room temperature and in liquid nitrogen for all the resistors except the 51 Ω and the 500 MΩ. The 51 Ω resistor was not tested because, using this method, it was not suppose to draw significant voltages. The 500 MΩ resistor would see very little current, but since it has to withstand 1000 V, we tested it to 1500 V. However, the Fluke multimeter reads only to 1000 V so we measured the voltage using the high voltage supply and took the 200 kΩ resistor into account.

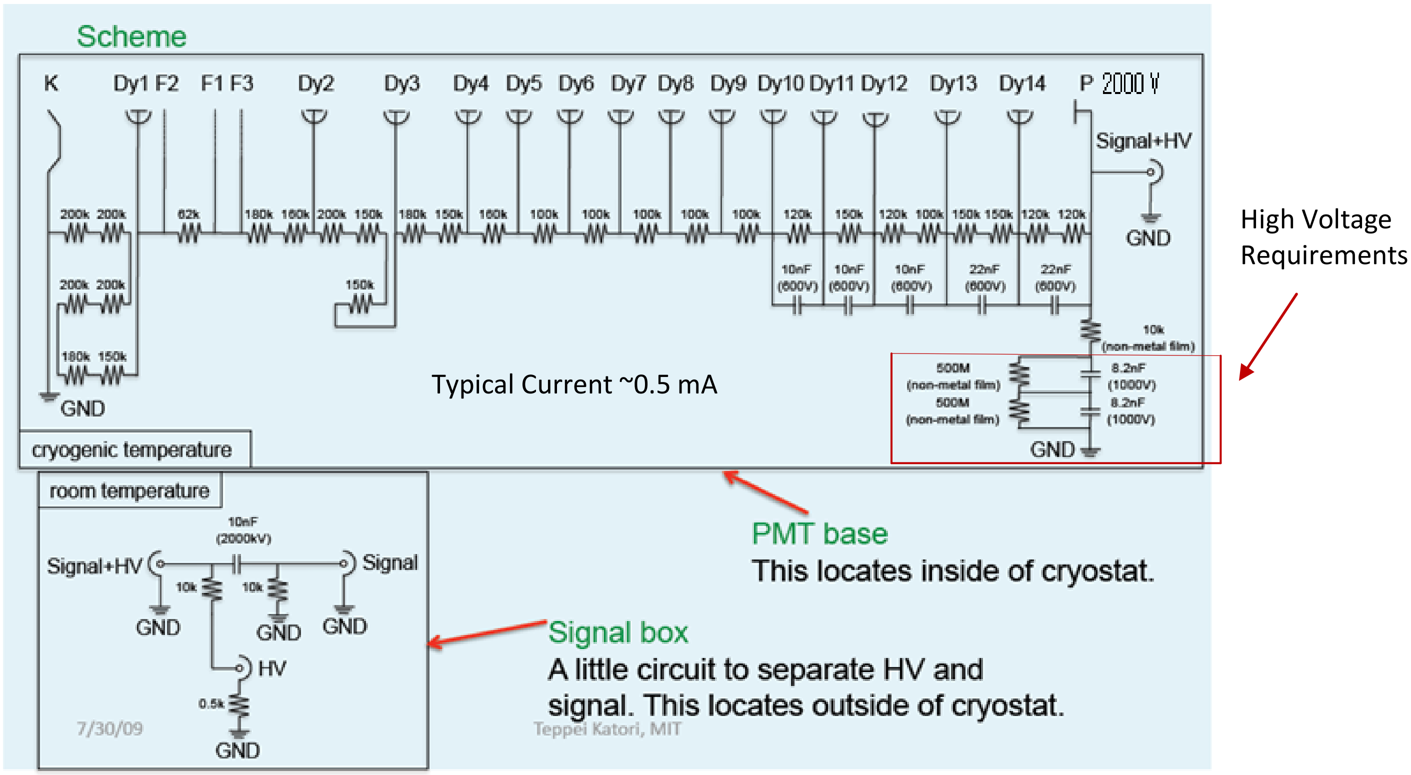

Figure 6a: MicroBooNE PMT base schematic

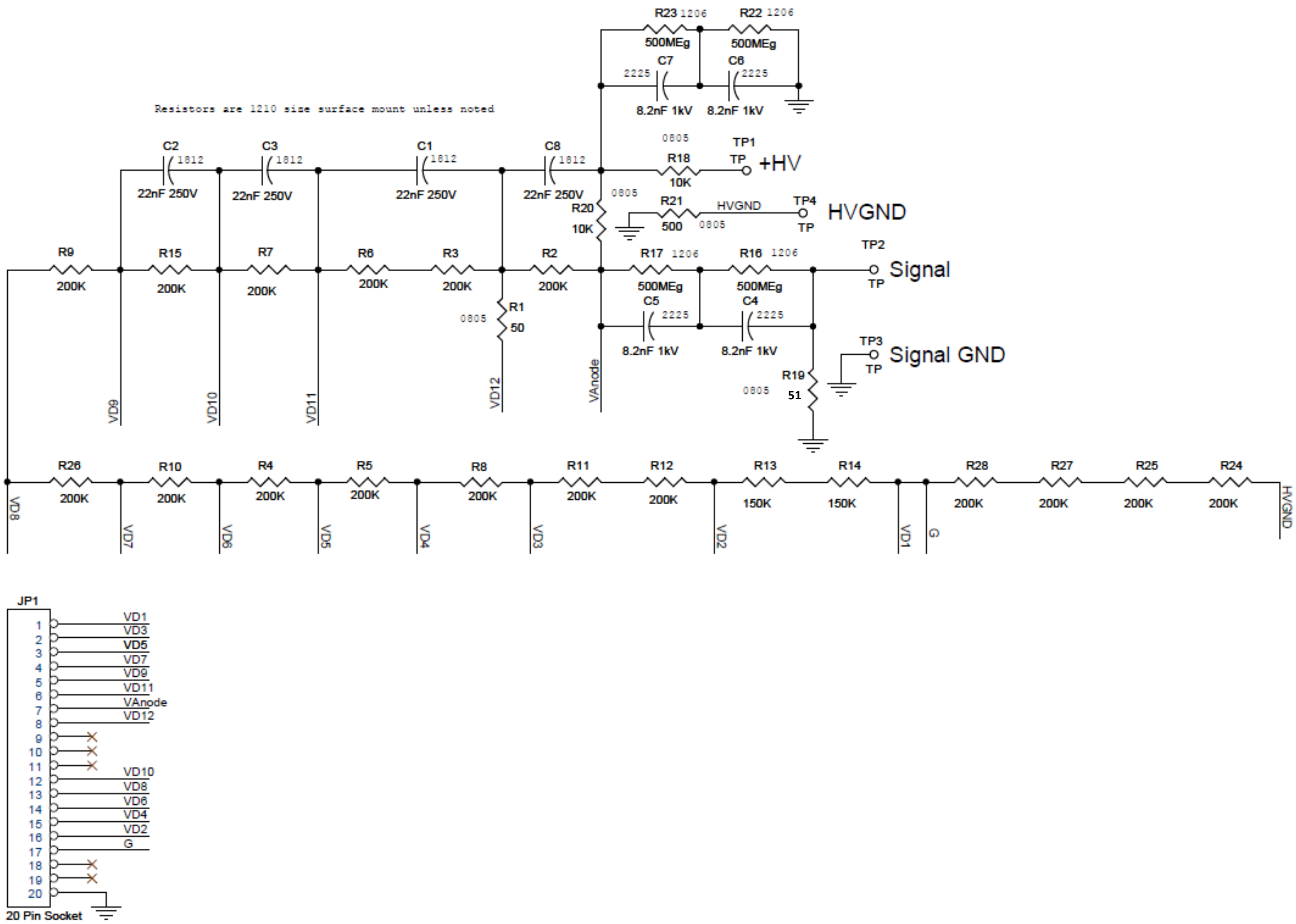

Figure 6b: R11065 base schematic

3. Results

i. Capacitance Test

In liquid nitrogen, each of the capacitances remained constant and corresponded to their room temperature counterparts (see Table 1).

Capacitor #	Capacitance					
	Room Temperature (nF)	Nitrogen: Cycle 1 (nF)	Nitrogen: Cycle 2 (nF)	Nitrogen: Cycle 3 (nF)	Nitrogen: Cycle 4 (nF)	Nitrogen: Cycle 5 (nF)
1	8.37	8.31	8.38	8.36	8.33	8.35
2	8.17	8.12	8.17	8.16	8.14	8.16
3	22.6	22.8	22.8	22.8	22.8	22.8
4	23.1	23.2	23.2	23.2	23.2	23.2

Table 1: Capacitances at Room Temperature and in Liquid Nitrogen.

ii. Voltage Test: Capacitors

None of the capacitors leaked current at either room or liquid nitrogen temperatures. At their appropriate voltages, the current through the capacitors was undetectable to the sensitivity of the high voltage supply, 1 nA. See Table 2 for results.

Capacitor #	Voltage (V)	Current at Room Temperature (mA)	Current in Liquid Nitrogen (mA)
1	2000	Undet.	Undet.
2	2000	Undet.	Undet.
3	500	Undet.	Undet.
4	500	Undet.	Undet.

Table 2: Voltages through Capacitors at Room and Liquid Nitrogen Temperatures. Undet.=<1 nA

iii. Resistance Test

The resistances were what the manufacturers claimed and remained consistent in liquid nitrogen (see Table 3).

Resistor #	Resistance (kΩ)		
	Claimed	Room Temperature	Liquid Nitrogen
1	51 Ω	51 Ω	51 Ω
2	51 Ω	51 Ω	51 Ω
3	150	150	150
4	150	150	150
5	200	200	200
6	200	200	200
7	270	270	271
8	270	270	271
9	470	470	470
10	470	471	471
11	560	560	562
12	560	560	562
13	620	620	620
14	620	620	620
15	500 MΩ	527 MΩ	575 MΩ

Table 3: Resistances at Room Temperature and in Liquid Nitrogen.

iv. Voltage Test: Resistors

The relationship between current, voltage, and resistance (Ohm's law)

$$\boldsymbol{V = IR} \qquad (1)$$

and the equivalent equation

$$\mathbf{R} = \frac{V}{I} \quad (2)$$

was used to determine whether the resistances stayed the same over different voltages. Each voltage and its corresponding current was substituted into Equation (2), and the results at both room and nitrogen temperatures show no significant changes in resistances except for the 500 MΩ (see Table 4). This resistor had a 9.5% increase in its resistance while in liquid nitrogen compared to when it was in room temperature. The highlighted rows are when the resistors were submerged in the nitrogen.

Resistor #	Measured Voltage (V)				Calculated Resistance (kΩ)			
	0 mA	0.3 mA	0.6 mA	0.8 mA	0	0.3 mA	0.6 mA	0.8 mA
1	--	--	--	--	--	--	--	--
2	--	--	--	--	--	--	--	--
3	0	44.6	89.4	119.1	--	148.7	149.0	148.9
	0	44.6	89.4	119.1	--	148.7	149.0	148.9
4	0	44.7	89.4	119.1	--	149.0	149.2	149.0
	0	44.7	89.5	119.2	--	149.0	149.2	148.9
5	0	59.5	118.8	158.6	--	198.3	198.0	198.3
	0	59.3	119.0	158.5	--	197.7	198.3	198.1
6	0	59.3	119.1	158.7	--	197.7	198.5	198.4
	0	59.4	119.0	158.5	--	198.0	198.3	198.1
7	0	80.4	160.4	214.1	--	268.0	267.3	267.6
	0	80.3	161.0	213.9	--	267.7	268.3	267.4
8	0	79.8	160.0	213.7	--	266.0	266.7	267.1
	0	80.7	160.8	214.5	--	269.0	268.0	268.1

Resistor #	Measured Voltage (V)				Calculated Resistance (kΩ)			
	0 mA	0.3 mA	0.6 mA	0.775 mA	0 mA	0.3 mA	0.6 mA	0.775 mA
9	0	139.9	278.7	359.9	--	466.3	464.5	464.4
	0	143.3	283.3	363.8	--	477.7	472.2	469.4
10	0	139.5	279.0	360.6	--	465.0	465.0	465.3
	0	143.6	284.5	365.6	--	465.0	465.0	47.2
11	0	166.0	332.1	428	--	553.3	553.5	570.3
	0	166.0	331.9	442	--	553.3	553.2	570.3
12	0	166.5	331.5	428	--	555.0	552.5	552.3
	0	166.2	332.4	429	--	554.0	554.0	553.5
13	0	183.5	367.8	478	--	611.7	613.0	616.8
	0	185.5	366.2	471	--	618.3	610.3	607.7
14	0	183.7	367.8	477	--	612.3	607.3	615.5
	0	184.8	364.4	470	--	612.3	613.0	615.5

Table 4a: Measured Voltages and Calculated Resistances at their Corresponding Currents for Resistors. Highlighted rows are for the results when the resistors were in liquid nitrogen.

Resistor #	Measured Current (mA)				Calculated Resistance (kΩ)			
	0 V	500 V	1000 V	1500 V	0	500 V	1000 V	1500 V
15	0	9.8e-4	1.91e-3	2.84e-3	--	508.2 MΩ	521.2 MΩ	526.2 MΩ
	0	9.8e-4	2.1e-3	3.13e-3	--	508.2 MΩ	474.2 MΩ	477.2 MΩ

Table 4b. Measured Currents and Calculated Resistances at their Corresponding Voltages. Highlighted rows are for the results when the resistor was in liquid nitrogen.

4. Conclusion

These resistors and capacitors performed as they should in liquid nitrogen: their capacitances and resistances remain constant, the capacitors do not leak current, and the resistors maintain their resistances across different voltages. While the 500 MΩ resistor had an increase in its resistance at liquid nitrogen temperature, this component can still be used as planned in the MicroBooNE base design. Since they are being used to stabilize voltage, and not as part of the dynode structure, a change in its resistance is acceptable. As such, all these components can be used the MicroBooNE and dark matter experiments.