<u>VLBA Memo 699</u>

Testing Helium Compressor Flow Capacity for Possible X-Band Upgrade

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Abstract

Most of the VLBA antennas have eight cryogenically cooled receivers. These receivers are cooled to cryogenic temperatures by GM cryocoolers that are connected to two helium compressors. Four of the receivers are connected to each of the compressors so that there are two independent cryogenic systems. The L-Band and S-Band use the larger model-350 cryocooler, while the other six receivers are cooled by the smaller model-22. The load is evenly distributed between the two compressors. Each system runs three model-22s and one model-350 cryocooler.

MIT/Lincoln Laboratory is interested in installing a new X-Band receiver on every VLBA antenna to work with the HUSIR radar project. The new receiver will have a broader bandwidth to include the radar return frequencies needed. NRAO is in the early stages of preparing a budgetary estimate for the new receiver design and determining what hardware changes are required and impact on cost. Designing a new X-band receiver will give the engineers a chance to replace the model-22 cryocooler with the much more reliable model-350. However, the larger cryocooler will require more pressurized helium from the compressor and it is not certain that the compressor has enough capacity to cope with the increased load.

To evaluate the capacity of the VLBA helium compressor, a test cryostat equipped with a model-350 cryocooler was installed at the Pie Town antenna effectively replacing the existing X-band receiver and its model-22. The test cryostat has heat resistors connected to the first and second stage of the cryocooler and temperature sensors on both locations. Once the test cryostat has cooled, a programmable power supply is used to apply a set of specific heat loads while the temperatures are recorded. The temperatures of the other three receivers and the compressor pressures are also monitored to understand the effects of the larger cryocooler on the rest of the system. The recorded data are analyzed and a recommendation can be made regarding the size of the compressor.

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1 Introduction

The NRAO has been approached by the MIT/Lincoln Laboratory to design and build a broadband X-band receiver for the VLBA. If the NRAO is presented with the opportunity to build a new X-band, the engineering team would like to make some changes to the current design. One of the most significant upgrades would be to replace the model-22 cryocooler with the larger and much more reliable model-350 cryocooler. During the many years of operation, the model-22 cryocooler has demonstrated poor reliability due to the elevated reciprocating speed of its displacer. The engineering team is proposing to use the model 350 cryocooler because it has more cooling capacity and because it runs at a third of the speed. The slower run speed has demonstrated an average cryocooler maintenance interval of about three times longer. Since the model-350 cryocooler requires more pressurized helium, it is important to determine if the compressor used currently has enough flow capacity. If it does not, the purchase of a third compressor or a higher capacity compressor would have to be added to the budget estimate of the X-Band upgrade.

2 Instrumentation

2.1 List of Test Instrumentation Used for the Test

1. Test cryostat

a. Model-350 GM two stage cold head

b. Lakeshore DT-670 temperature sensors, one per stage

c. Heat resistors, 40Ω on the first stage 100Ω on the second stage

d. Teledyne DV6-M vacuum gauge

2. Model-350 cold head driver
3. LakeShore model 224 temperature monitor
4. B&K Precision 9174B dual channel programmable DC Power Supply
5. TC-500 thermocouple vacuum gauge reader
6. Dell Laptop with LabVIEW executable
7. Small APC UPS

2.2 Schematic

The Figure 1 shows a simplified schematic of the test set

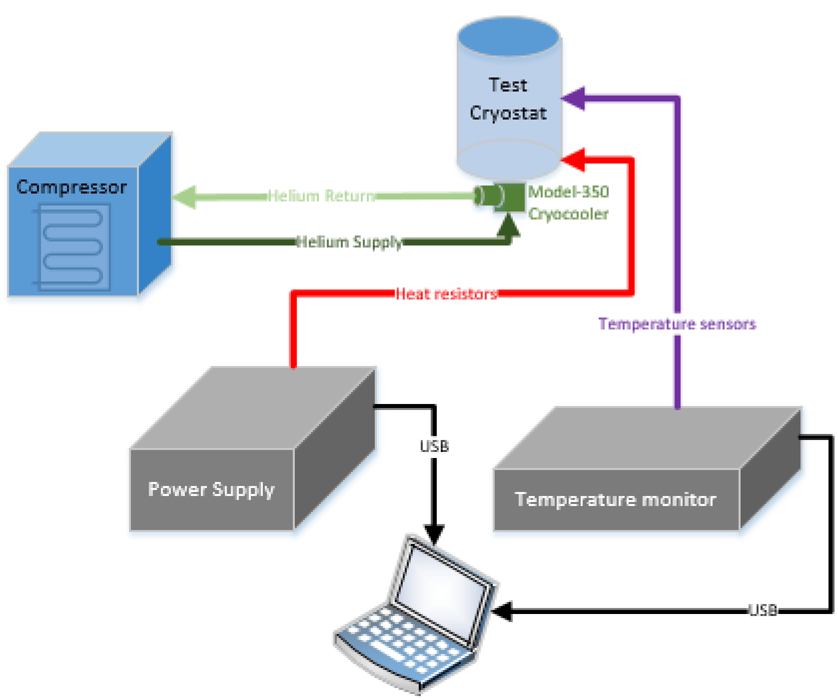

Figure 1. Test set Schematic

3 Measurement

3.1 Set-up

Before starting the test, the helium compressor supply pressure was adjusted close to 300psi on the analog gauge. The test cryostat and the test instruments were lifted and installed on the upper deck of the VLBA antenna vertex room. The helium lines and vacuum hose were removed from the existing VLBA X-band receiver and connected to the test cryostat. The connections from the temperature monitors, the power supply to the test cryostat and the laptop were established.

3.2 Cool Down

After powering up the test instrumentation, we checked the communication between the laptop, the temperature monitor and the power supply. The test software was started and the vacuum pump turned ON to begin the test cryostat pump down. When the vacuum pressure dropped below 10^{-2} mbar, the cold-head was turned on and the temperatures monitored to ensure that the test cryostat temperatures were dropping. When the second stage reached 70K, the solenoid valve was closed and the vacuum pump turned off. The laptop kept monitoring the temperatures until they reached equilibrium at which point the cool down phase ended.

3.3 Load Map

At this stage of the proposal, the broadband X-band is just a concept and the actual thermal loads are unknown. The purpose of a load map is to establish a range of heat loads for the first and second stages and measure the temperatures for various load combinations within that range. We decided on a 16 point load map with a first stage load covering the 0-15W range in 5W step and a second stage changing from 0-3W in 1W step.

1pt [0W,0W]	2pt [5W,0W]	3pt [10W,0W]	4pt [15W,0W]
8pt [0W,1W]	7pt [5W,1W]	6pt [10W,1W]	5pt [15W,1W]
9pt [0W,2W]	10pt [5W,2W]	11pt [10W,2W]	12pt [15W,2W]
16pt [0W,3W]	15pt [5W,3W]	14pt [10W,3W]	13pt [15W,3W]

Table 1. Load Map Points [1^{st} stage power, 2^{nd} stage power]

4 Results

4.1 Load Map

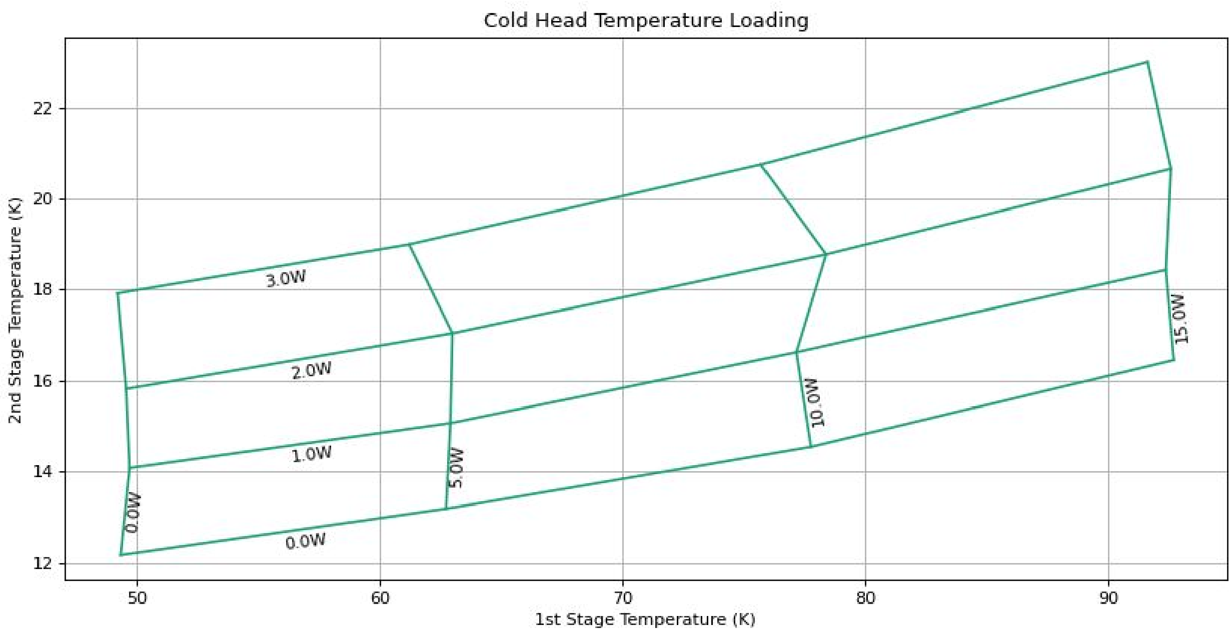

Figure 2. Test Cryostat Load Map (Model-350 cryocooler)

The load map shows that the test cryostat stayed cold during the entire test. The highest temperatures were 92K and 23K for 15W, 3W respectively. If the goal is to keep the temperature of the first stage below 80K and the temperature of the second stage below 20K, the corresponding thermal loads shall not exceed 11W and 2.4W.

4.2 Impact on the other Receivers

It is important to see how swapping the X-band model-22 cold head with the larger model-350 from the test cryostat affected the compressor and the cooling of the other receivers (L-band, Q-band and W-band).

He compressor A	He Compressor B
L-Band / 20cm, cold head model-350	S-Band / 13cm, cold head model-350
X-Band / 4cm, cold head model-22	C-Band / 6cm, cold head model-22
Q-Band / 7mm , cold head model-22	K-Band /13mm, cold head model-22
W-Band / 3mm, cold head model-22	Ku-Band /2cm, cold head model-22

Table 2. VLBA Compressors and Receivers Configuration

The temperatures of the VLBA receivers were monitored and stored using the standard antenna M&C electronics that has a much slower sampling rate than the test instrumentation used to monitor the test cryostat.

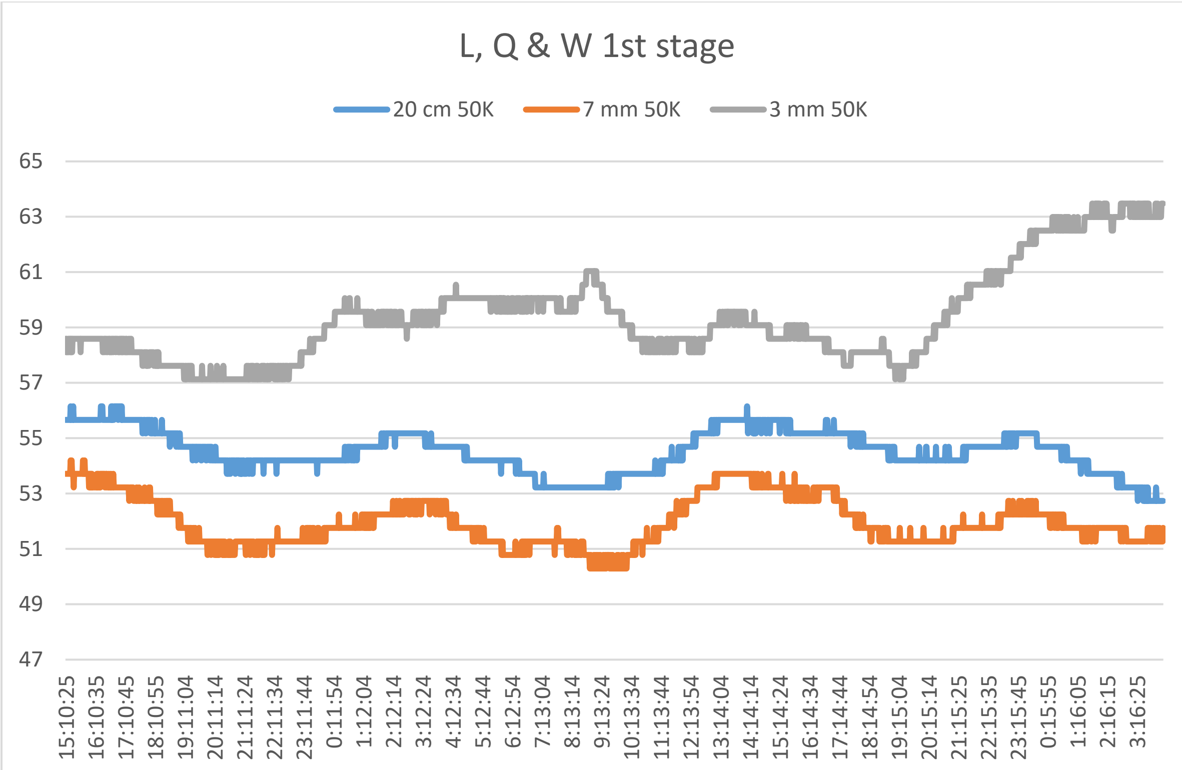

Figure 3. Temperature of the VLBA L-Band, Q-Band and W-Band First Stage

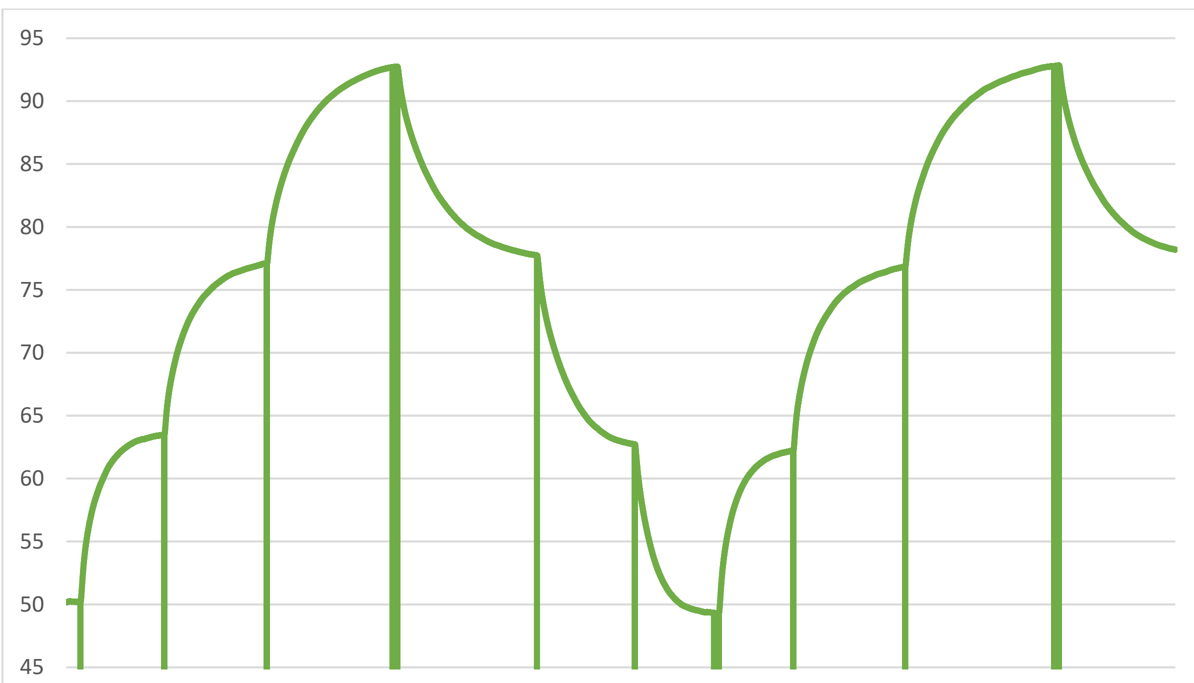

Figure 4. Test Cryostat Temperature of the First Stage

The Figure 4 shows the temperature of the first stage on test cryostat as the heat load starts at 0W/50K and goes up to 15W/93K then goes back down to 0W/50K and finally goes back up to 15W/93K.

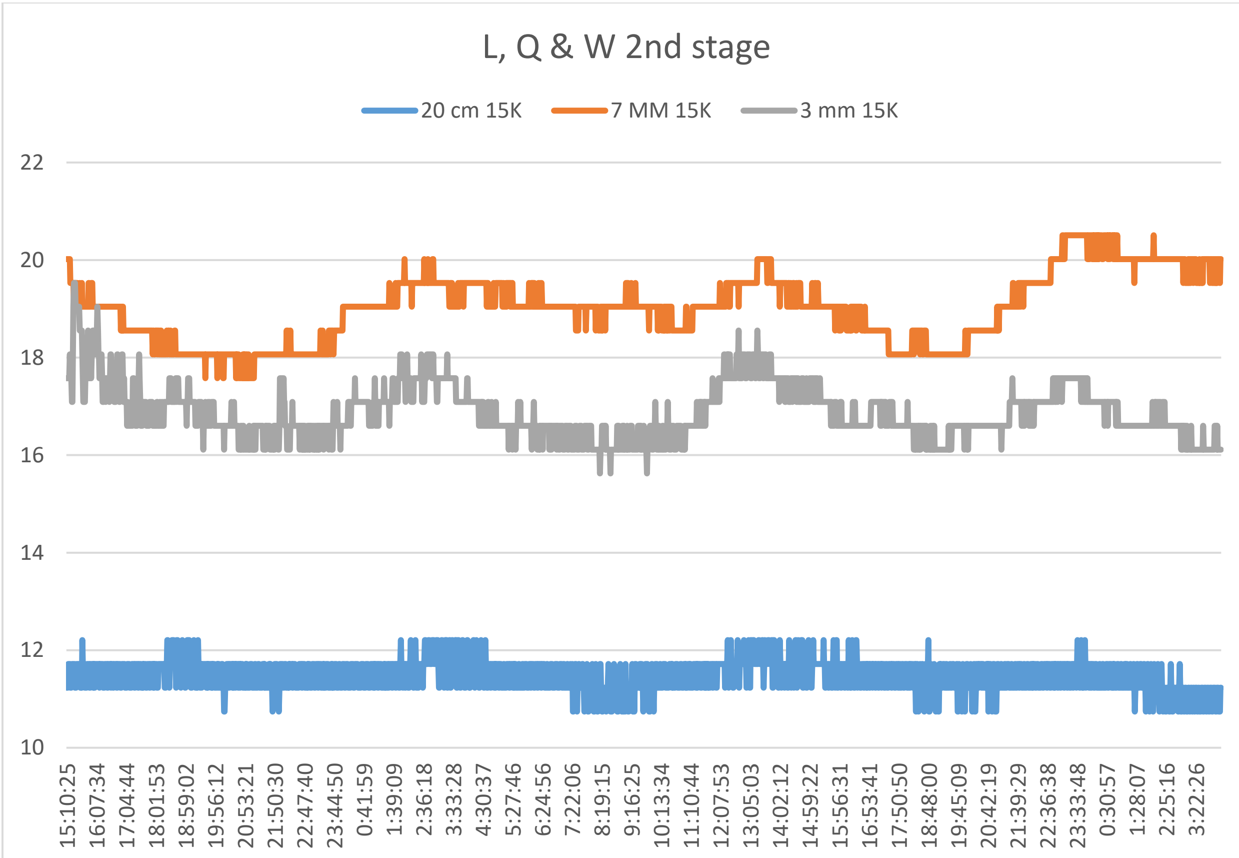

Figure 5. Temperature of the VLBA L-Band, Q-Band and W-Band Second Stage

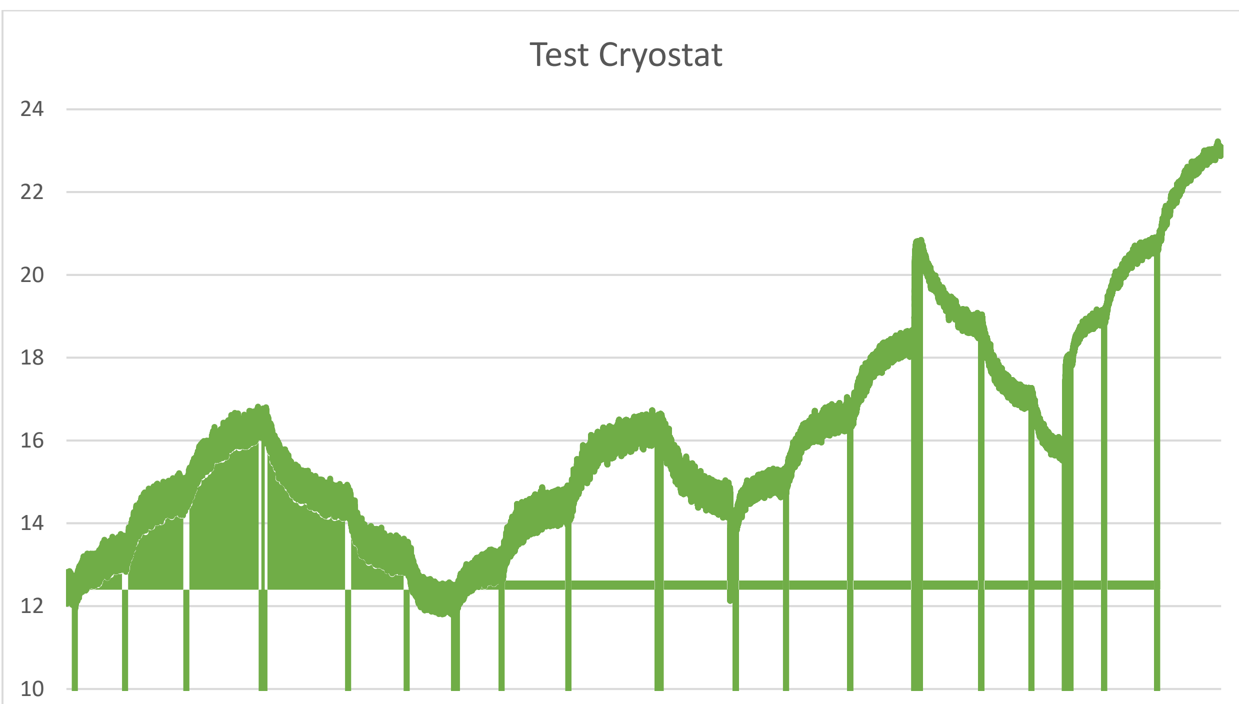

Figure 6. Test Cryostat Temperature of the Second Stage

It is interesting to notice in Figures 3 through 6 that the temperatures of the VLBA receivers vary in phase opposition with the temperature of test cryostat. When the test cryostat (1st and 2nd stage) gets warmer, the other three receivers get colder. The inverse is true when the test cryostat cools. This phenomenon can be explained by the distribution of the helium flow generated by the compressor between the various cryocoolers. When the test cryostat gets warmer, the amount of helium that circulates thru the model-350 cryocooler diminishes which in turn allows more flow through the other three cryocoolers. More flow means more cooling power which translates into a drop in temperatures.

It is also interesting to see how the two receivers equipped with model-22 cryocoolers are a lot more sensitive to the helium flow variations. This indicates that the cooling margin for these two receivers is a lot smaller. The model-22 has just enough cooling capacity on the second stage to keep the Q-Band and W-Band temperature below 20K, meanwhile the L-Band with the larger model-350 cryocooler remains almost undisturbed.

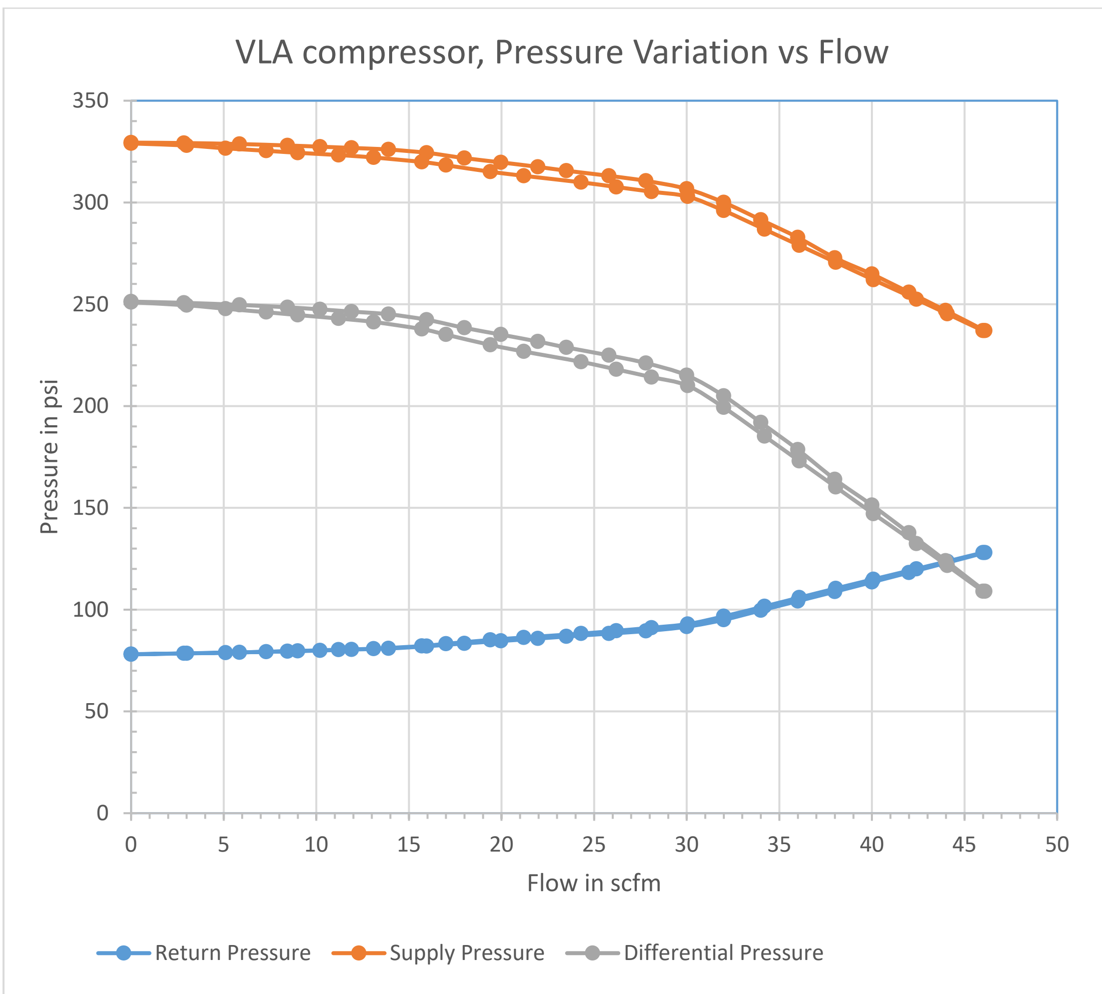

Figure 7. Helium Compressor Pressures Variation VS Flow

The curves in Figure 7 are generated using a needle valve that is placed between the supply and the return lines in place of the cryocoolers. Initially the valve is closed and the entire helium flow has to go thru the compressor bypass valve. A calibrated flow meter measures the flow thru the needle valve and pressure sensors monitor the supply and return pressures. As the needle opens, more and more pressurized helium flows thru it instead of the bypass valve and the differential pressure drops. Around 30 scfm, there is an inflection of the curve and the pressures start to change more rapidly with the flow. This inflection indicates the closure of the bypass valve and full flow circulation thru the needle valve. As the needle valve is opened further, the opening offers less and less resistance to the pressurized helium, the flow goes up and the differential pressure goes down. It is not recommended to exceed 130 psig on the return pressure side. Once the pressure reaches this value, the process is reversed and the needle valve is closed slowly. A small amount of hysteresis is observed on the pressures between the opening and closing sequences of the needle valve, but the inflection happens at the same flow value.

For the experiment, the static pressure of the compressor (compressor turned off) was set to 180 psig but at the end of the test the static pressure was only 170psig. It is unclear what happened, but I believe that some of the pressure might have been lost at the beginning of the test when the needle valve was closed and the entire flow was going thru the bypass valve. This is the time when the supply pressure is the highest and the internal relief valve might have let some of the pressure escape. Because it takes several minutes for the supply pressure to stabilize at startup, some helium could have been lost through this relief valve.

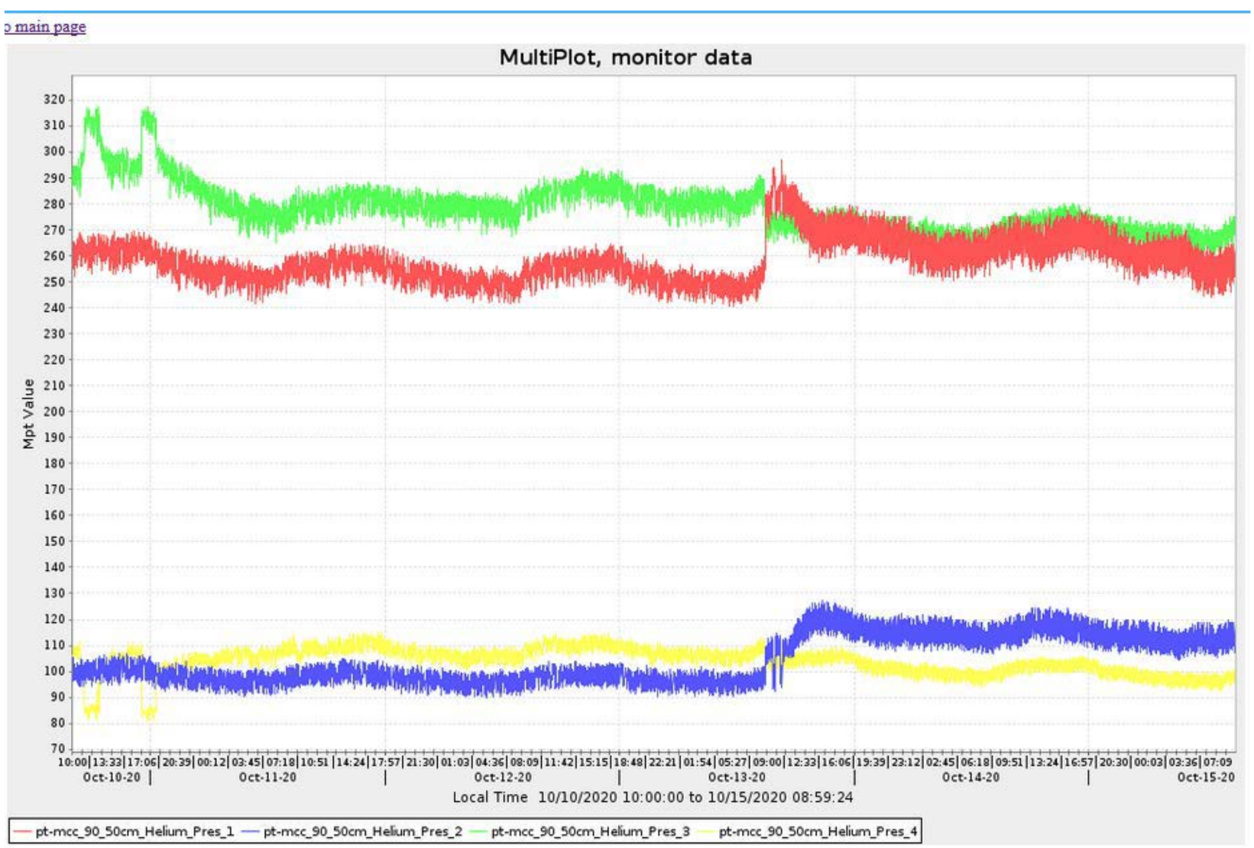

Figure 8. Pie Town Antenna Helium Compressor Pressures Before and During the Test

The pressures of the compressor A circuit are shown in blue (return) and red (supply) in Figure 8. The supply pressure was adjusted on October 13 just before the start of the test (rapid jump in pressure seen at 10:00 am). During the test period, both compressors had similar supply pressures although the compressor A return pressures are higher. This is consistent with the fact that compressor A has to feed two model-22 and two model-350 cold heads while the compressor B has three model-22 and a single Model-350. As seen in Figure 7, when the flow increases the differential pressure drops. Below the inflection point in the curve, the differential curve has a slope of -0.15 scfm/psi.

	Compressor A	Compressor B
Average Supply Pressure	263.97	269.86
Average Return Pressure	114.79	100.14
Average Differential pressure	149.18	169.72

Table 3. Compressor A & B average pressures during the test.

The compressor A differential pressure is 20 psi lower than the compressor B which gives a 3 scfm higher flow. The following numbers need to be confirmed but the model-22 cold head is rated at 9 scfm flow while the model-350 is rated at 12.5 scfm. The test performed measured 3 scfm difference in flow.

From Figure 7, a 150psi differential pressure corresponds to a 40scfm helium flow. This is only really valid for a specific static pressure (170 psi) and a specific compressor, but as a first order of approximation we are very close to the 43 scfm expected value (2x9 scfm+ 2x12.5 scfm = 43 scfm).

To quantize the impact of the larger model-350 cryocooler on the cooling of the other three receivers, the temperatures of the first and second stages for the three VLBA receivers and the test cryostat with heat loads of [10w,2W] are averaged and compared with the temperatures collected after the test with the X-band cold.

Receiver During Test	***Temp K 1st Stage***	***Temp K 2nd Stage***	***Receiver After Test***	***Temp K 1st Stage***	***Temp K 2nd Stage***	***Δ 50K***	***Δ 15K***
Test Cryostat 10W 1st 2W 2nd	76.806	14.406	**4 cm**	52.848	18.701	n/a	n/a
20 cm	54.305	11.536	**20 cm**	46.391	9.814	7.914	1.722
7 mm	51.408	16.679	**7 mm**	47.375	14.181	4.033	2.498
3 mm	59.977	19.283	**3 mm**	61.084	17.997	1.107	1.286

Table 4. Temperature comparison table during test [10W, 2W] and after test

All three receivers saw an increase in temperature due to the higher flow demand and drop in pressure. The 20cm saw the largest increase on the first stage with 7.9K while the 7mm saw the largest increase on the second stage with 2.5K. While the changes were noticeable, the temperatures were kept within acceptable range.

5 Conclusion

The purpose of the experiment was to answer the question, "Does a VLBA helium compressor have enough capacity to run two model-22 and two model-350 cryocoolers on the same circuit?" When the model-22 cold head from the X-band was replaced with the model-350 from the test cryostat, we did see an increase in temperature on the other three receivers and a drop in differential pressure. However, the test cryostat did get cold and the other receivers stayed within an acceptable temperature range. The higher required flow from the model-350 cryocooler generates the drop in differential pressure and consequently the lower differential pressure explains the rise in temperature seen on the other receivers. Based on the results of this experiment, it seems that the compressor has enough capacity to accommodate the larger cryocooler, but we are clearly pushing the limit of its capability.

A possible solution would be to introduce a dynamic observing schedule for the W-Band since it is only used sporadically. The receiver would only be made available during a limited time of the year and it would be cooled on demand for a scheduled observation. The rest of the time it would stay warm which would help reduce the load on the compressor and reduce wear and tear on the W-band cryocooler.