EVLA Memo #168
Assessing the Impact of Using Three Cryogenic Compressors on the Performance of the EVLA

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April 6, 2013

Abstract

We present dewar temperature and system temperature measurements for the eight cryogenically cooled receivers of a subset of four EVLA antennas that have undergone a reconfiguration to use three cryogenic compressors instead of four. We compare the changes in the system temperatures in these antennas with those obtained from a subset of eight other EVLA antennas that have not undergone such a reconfiguration. The results show that the S, Ku, and K-band receivers have a small, but significant loss of sensitivity because of the change in the compressor configuration. The net loss in the sensitivity is $\sim$ 3.4%, 5.1%, and 2.7% for the S, Ku, and K-bands, respectively. Two other receivers, namely the C and X-band receivers, also show some degradation ($\lesssim$ 2%) in their sensitivity. After the reconfiguration, the S, Ku, and K-band receivers have been connected to compressor Unit A, while the C and X-band receivers to compressor Unit B along with the Q-band receiver. Considering the overall load on compressor Unit A and the high thermal load of the S-band receiver, we suggest connecting the S, Ku, and Q-band receivers to this compressor unit. The K-band receiver will then be connected to compressor Unit B along with the C and X-band receivers.

1 Introduction

Each EVLA antenna has a set of eight cryogenically cooled receivers that cover the continuous frequency range 1–50 GHz. Table 1 lists the types and the loads of the cryogenic refrigerators used to cool these receivers.

Refrigerator Type	Model 1050	Model 350	Model 22
Receiver	L	S, C, X, Ku, K, Ka	Q
Load (SCFM)	28	17	9

Table 1: The cryogenic refrigerators of the EVLA receivers and their respective loads in units of Standard Cubic Feet per Minute (SCFM).

There are four compressor units (A through D) available for these eight cryogenic receivers. Laboratory measurements show that each compressor unit has a nominal capacity of 60 SCFM. In mid 2012, it was suggested that modifying the cryogenic compressor manifolds and using only three of the four compressors may have a minimal impact on the sensitivity of the receivers. Table 2 lists the differences between the configuration that uses all four compressor units and the configuration that uses only three compressor units. The receivers in both configurations were grouped to evenly distribute the compressor load as much as possible.

Compressor Unit	4 Compressor Configuration		3 Compressor Configuration	
	Receivers	Estimated Load (SCFM)	Receivers	Estimated Load (SCFM)
Unit A	S, Ku	34	S, Ku, K	51
Unit B	K, Q	26	C, X, Q	43
Unit C	C, X	34	*N/A*	—
Unit D	L, Ka	45	L, Ka	45

Table 2: The distribution of the EVLA receivers between the 4 compressor configuration (4CC) and the 3 compressor configuration (3CC), and the load per compressor in each configuration. The nominal capacity of each compressor unit is 60 SCFM.

As seen in Table 2, two of the compressors (Units A and B) have a three receiver load in the three compressor configuration (hereafter 3CC) instead of the two receiver load in the four compressor configuration (4CC). One compressor (Unit D) remains connected to the same two receivers in both configurations, while compressor Unit C is turned off in the 3CC. As a result of this reconfiguration, three Model 350 refrigerators are connected to Unit A, while two Model 350 refrigerators and one Model 22 refrigerator are connected to Unit B.

In order to assess the impact of using the 3CC on the sensitivity of the receivers connected to Units A and B, we have carried out several test observations utilizing all the cryogenically cooled receivers of the EVLA. Of particular interest in these tests was to check if there will be any loss in the sensitivity of the receivers that are connected to compressor Unit A which has the 2nd largest EVLA receiver (i.e., the S-band receiver) and therefore the 2nd largest thermal load after L-band. Also, the tests would verify the expectation that no change in sensitivity should be seen on the two receivers that are connected to compressor Unit D for which no compressor reconfiguration was made.

2 Observations

Four separate EVLA observations were carried out on 4, 5, 6, 7 December 2012 in A-configuration. Each observing session was 0.5 hr, and all four sessions were observed under clear weather conditions after midnight local time to minimize variations in the system temperature due to various external effects. The calibrator source J0217+7349 was targeted using all eight cryogenically cooled receivers of the EVLA at the frequencies listed in Table 3. Each frequency band was set up to deliver four 128 MHz sub-bands, one from each 8-bit intermediate frequency (IF) passband (i.e., A0, C0, B0, and D0). All four sub-bands were tuned to the same frequency. In the following sections, we refer to these data as IF A, IF B, IF C and IF D. The scan length at each frequency was 2 min. The scans at the high frequencies (≥ 15 GHz) were preceded by a reference pointing scan at X-band.

In the first two observing sessions (hereafter sessions "PRE1" and "PRE2"), all the EVLA antennas were in the 4CC. After the successful conclusion of these two sessions, and during the day of December 5, members of the cryogenic group reconfigured the compressors on antennas ea10, ea23, ea25, and ea28, making them operate on the 3CC (see Table 2). Following this reconfiguration, two more sessions were observed in the following two consecutive nights (hereafter sessions "POST1" and "POST2"). All the other antennas in the array operated on the 4CC in all four sessions.

Receiver Band	Sub-band Center Frequency (MHz)
L (1–2 GHz)	1452
S (2–4 GHz)	3084
C (4–8 GHz)	4896
X (8–12 GHz)	8296
Ku (12-18 GHz)	15000
K (18–26.5 GHz)	24436
Ka (26.5–40 GHz)	33496
Q (40–50 GHz)	41000

Table 3: Summary of the sub-band center frequencies per receiver band. Each band had four 128 MHz sub-bands, one from each 8-bit intermediate frequency (IF) passband. The four sub-bands of each receiver band were tuned to the same frequency.

3 Results and Analysis

The data were loaded into AIPS using BDF2AIPS, and the system temperature T_{sys} values were obtained from the switched power measurements. In the switched power system of the EVLA, a small, known and stable amount of power, P_{cal}, is periodically added to the antenna signal. This signal is amplified and then subdivided into sub-bands at the station boards of the WIDAR correlator. At each sub-band, the software synchronously determines the powers in both the 'cal on' and 'cal off' states, i.e., P_{on} and P_{off}.

The system temperature can then be computed as follows:

$$T_{sys} = \frac{(P_{on} + P_{off})}{2(P_{on} - P_{off})} \times T_{cal} \tag{1}$$

where T_{cal} is the switched noise power expressed in units of K following the conversion between spectral power and temperature. Refer to the EVLA Memo # 145 (Perley, R. 2010) for all the details regarding the switched power system.

The T_{sys} values were obtained for all the four IFs (A, B, C, D) of the four antennas of interest (ea10, ea23, ea25, and ea28) and for each of the four observing sessions separately, i.e., for the two PRE sessions and the two POST sessions. Hereafter, we refer to these four antennas as *Reconfigured Antennas*. The T_{sys} values of eight other antennas that did not undergo any compressor reconfiguration during all four sessions were also obtained and for each of their four respective IFs. Of these eight, two antennas were chosen to be near each one of the four *Reconfigured Antennas* to minimize any system temperature variations due to the location of the antennas in the most extended (A) configuration of the array. Hereafter, we refer to these eight antennas as *Control Antennas*, because they serve as a reference while we attempt to quantify any changes in the T_{sys} of the *Reconfigured Antennas*.

Using the T_{sys} values, we have performed various statistical analyses. In this process, we excluded antennas that had broken or unstable switched power systems at certain receiver bands. We have chosen to compare the results between PRE1 and POST2 sessions, and between the PRE2 and POST1 sessions, to obtain two independent assessments on the effects of the compressor reconfiguration.

In addition to measuring the change in the T_{sys} for each receiver during these sessions, we obtained the change in the monitored 15 K stage temperature, or the dewar temperature T_d, before and after the reconfiguration of the compressors was performed on December 5.

3.1 The change in T_d due to the compressor reconfiguration

Measurements of the dewar temperature T_d were obtained on the four *Reconfigured Antennas* and their eight cryogenically cooled receivers before and after the compressor reconfiguration (from 4CC to 3CC). In Table 4, we report the mean change in the dewar temperatures per receiver band.

Receiver	$< T_{d\text{-}POST} - T_{d\text{-}PRE} >$ (K)
L	$+0.00 \pm 0.35$
S	$+4.50 \pm 0.52$
C	$+1.50 \pm 1.03$
X	$+2.25 \pm 0.35$
Ku	$+6.38 \pm 0.67$
K	$+3.13 \pm 0.60$
Ka	-0.13 ± 0.60
Q	$+0.38 \pm 0.60$

Table 4: The mean change in the dewar temperature T_d of the four *Reconfigured Antennas* due to the modification of the compressor configuration. PRE and POST are of the 4CC and 3CC, respectively.

The results show that the dewar temperatures of the S, C, X, Ku, and K-band receivers have increased in the 3CC. Three of these receivers — S, Ku, and K, which are connected to compressor Unit A, show the most notable changes. The C and X-band receivers are connected to compressor Unit B along with the Q-band receiver. While the change in T_d at X-band is statistically significant, it is only $\sim 1.5\sigma$ at C-band. The change in T_d of the Q-band receiver is very small and statistically insignificant. As expected, the dewar temperatures of the L and the Ka-band receivers have not changed.

3.2 The change in T_{sys} between PRE1 and POST2

For each of the eight receivers, the differences of the mean values of the T_{sys} between the PRE1 and POST2 sessions for each of the four *Reconfigured Antennas* and their four IFs were calculated. These two sessions are separated by 72 hours. Similar calculations were performed for the eight *Control Antennas*. From the resulting numbers, and for each group of antennas, an overall mean value was computed to quantify the change in the T_{sys} between the PRE1 and POST2 sessions for each receiver band. Finally, the values obtained for the *Control Antennas* were subtracted from the values of the *Reconfigured Antennas* to obtain the "net change" in the T_{sys} that could be attributed to the compressor reconfiguration. The results, per receiver band, are listed in Table 5. Positive values suggest that the T_{sys} became higher due to the modification from 4CC to 3CC.

As seen in Table 5, three receivers show the most significant change in T_{sys}. These are the S, Ku, and K-band receivers. The range of the change is 1.00–1.72 K.

3.3 The change in T_{sys} between PRE2 and POST1

For each of the eight receivers, the differences of the mean values of the T_{sys} between the PRE2 and POST1 sessions for each of the four *Reconfigured Antennas* and their four IFs were calculated. These two sessions are separated by 24 hours. Similar calculations were performed for the eight *Control Antennas*. From the resulting numbers, and for each group of antennas, an overall mean value was computed to quantify the change in the T_{sys} between the PRE2 and POST1 observing sessions for

Receiver	$<< T_{sys\text{-}POST2}> - < T_{sys\text{-}PRE1}>>$ *Reconfigured Antennas* (K)	*Control Antennas* (K)	Net Change in T_{sys} (K)
L	-0.31 ± 0.32	$+0.08 \pm 0.42$	-0.39 ± 0.53
S	$+1.11 \pm 0.09$	$+0.11 \pm 0.24$	$+1.00 \pm 0.26$
C	$+0.53 \pm 0.20$	$+0.07 \pm 0.22$	$+0.46 \pm 0.30$
X	$+0.46 \pm 0.26$	-0.06 ± 0.14	$+0.52 \pm 0.30$
Ku	$+1.86 \pm 0.16$	$+0.14 \pm 0.14$	$+1.72 \pm 0.21$
K	$+6.24 \pm 0.16$	$+4.94 \pm 0.23$	$+1.30 \pm 0.28$
Ka	$+1.18 \pm 0.18$	$+1.44 \pm 0.14$	-0.26 ± 0.23
Q	$+0.50 \pm 0.73$	$+0.06 \pm 0.25$	$+0.44 \pm 0.77$

Table 5: The change in T_{sys} between the PRE1 and POST2 observing sessions (72 hour difference), and the net change upon subtracting the values of the *Control Antennas* from the *Reconfigured Antennas*. Positive values suggest that the T_{sys} became higher due to the modification from 4CC to 3CC.

each receiver band. Finally, the values obtained for the *Control Antennas* were subtracted from the values of the *Reconfigured Antennas* to obtain the "net change" in the T_{sys} that could be attributed to the compressor reconfiguration. The results, per receiver band, are listed in Table 6. Positive values suggest that the T_{sys} became higher due to the modification from 4CC to 3CC.

As seen in Table 6, and consistent with the results presented in §3.2 and Table 5, the S, Ku, and K-band receivers show the most significant change in T_{sys}.The range of the change is 1.02–1.43 K.

Receiver	$<< T_{sys\text{-}POST1}> - < T_{sys\text{-}PRE2}>>$ *Reconfigured Antennas* (K)	*Control Antennas* (K)	Net Change in T_{sys} (K)
L	$+0.34 \pm 0.79$	$+0.26 \pm 1.07$	$+0.08 \pm 1.33$
S	$+1.15 \pm 0.10$	$+0.13 \pm 0.19$	$+1.02 \pm 0.21$
C	$+0.55 \pm 0.21$	$+0.23 \pm 0.25$	$+0.32 \pm 0.33$
X	$+0.64 \pm 0.25$	-0.06 ± 0.14	$+0.70 \pm 0.29$
Ku	$+1.34 \pm 0.17$	-0.02 ± 0.14	$+1.36 \pm 0.22$
K	-1.37 ± 0.14	-2.80 ± 0.22	$+1.43 \pm 0.26$
Ka	-0.85 ± 0.19	-0.39 ± 0.14	-0.46 ± 0.24
Q	-0.90 ± 0.43	-0.88 ± 0.18	-0.02 ± 0.47

Table 6: The change in T_{sys} between the PRE2 and POST1 observing sessions (24 hour difference), and the net change upon subtracting the values of the *Control Antennas* from the *Reconfigured Antennas*. Positive values suggest that the T_{sys} became higher due to the modification from 4CC to 3CC.

3.4 The net change in T_{sys} between PRE and POST sessions

In light of the consistent results obtained in §3.2 and §3.3, in Table 7 we present the average net change in T_{sys} obtained for each receiver from the net changes seen in the PRE and POST session pairs (Tables 5 and 6). Again, positive values suggest that the T_{sys} became higher due to the modification from 4CC to 3CC.

Receiver	Average Net Change in T_{sys} (K)
L	-0.16 ± 0.72
S	$+1.01 \pm 0.17$
C	$+0.39 \pm 0.22$
X	$+0.61 \pm 0.21$
Ku	$+1.54 \pm 0.15$
K	$+1.37 \pm 0.19$
Ka	-0.36 ± 0.17
Q	-0.21 ± 0.45

Table 7: The average net change in T_{sys} between the PRE and POST session pairs. Positive values suggest that the T_{sys} became higher due to the modification from 4CC to 3CC.

4 Discussion

The monitored 15 K stage temperature, or the dewar temperature T_d, revealed notable (3–6 K) and statistically significant changes in three receivers — S, Ku, and K-bands (Table 4). Moreover, the C and X-band receivers showed a moderate change in T_d, and on the order of ~2 K.

The average net change in the T_{sys} (Table 7) showed that the S, Ku, and K-band receivers have noticeable ($\gtrsim$ 1 K) and statistically significant increases in their T_{sys} due to the change of the compressor configuration from 4CC to 3CC. The C and X-band receivers showed T_{sys} changes of $\lesssim$ 0.6 K. We note that the correlation between T_d and T_{sys} is not known for any of these eight receivers. This correlation needs to be determined for each receiver through careful laboratory measurements.

The S, Ku, and K-band receivers have been connected to the same compressor (Unit A) after the reconfiguration. These receivers have Model 350 refrigerators. Therefore compressor Unit A has the highest overall load in the 3CC. Also, the S-band receiver, which is the 2nd largest receiver, has a significant thermal load. Note that the largest receiver, namely the L-band, has the highest thermal load among all the EVLA receivers, while the smallest receiver, the Q-band, has the lowest thermal load. After the reconfiguration, the C and X-band receivers, which both have Model 350 refrigerators, have been connected to compressor Unit B along with the Q-band receiver and its Model 22 refrigerator.

The increase in the T_{sys} of the S, Ku, and K-band receivers due to the change in the compressor configuration from 4CC to 3CC is small, but significant. Assuming average T_{sys} values of 30, 30, and 50 K for the S, Ku, and K-bands, the increase in the T_{sys}, and therefore the loss in the sensitivity, is ~ 3.4%, 5.1%, and 2.7%, respectively. The C and X-band receivers, which are connected to compressor Unit B along with the Q-band receiver, also show some degradation in their sensitivities, while the Q-band receiver does not. Assuming average T_{sys} values of 30 K for the C and X-band receivers, the loss in the sensitivity is ~ 1.3% and 2.0%, respectively. The L and Ka-band receivers, and as expected, show no loss of sensitivity.

For compressor Unit A, we speculate that the reason for the higher T_d and T_{sys} values of its receivers (S, Ku, K) in the 3CC is the combination of having a high overall load, and the presence of a receiver that has a significant thermal load. An alternative compressor reconfiguration would be to connect S, Ku and Q-bands to Unit A, and C, X, and K-bands to Unit B. This will result in a load of 43 SCFM on Unit A and 51 SCFM on Unit B. Even though Unit B will have the highest overall load, Unit A will keep the high-thermal-load S-band receiver.

5 Acknowledgements

We would like to thank D. Gerrard for providing the data of the dewar temperatures, and K. Sowinski for helpful discussions.