SpaceX-VLA Alamo Pilot Results

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Abstract

Since 2022 the NRAO has been conducting observations to determine the impact of a limited number (59) of Starlink User Terminals (UTs) that are operating on the Alamo Navajo Reservation. In coordination with the NRAO, the UTs were installed to both help provide reliable internet access to families who previously did not have broadband internet access and to help the NRAO study how the RFI environment around the Very Large Array (VLA) could be impacted by the presence of such devices that have active uplink and downlink transmissions. These UTs provide uplink services within the radio spectrum at 14.0–14.5 GHz and receive downlink signals from the Starlink constellation at 10.7–12.7 GHz. Initial test results were presented in De Pree et al., 2023a and De Pree et al., 2023b. Since then, monitoring has continued at regular intervals. Here we describe this ∼3 year monitoring project and report our findings on how the UTs and associated signals affect data taken with the VLA.

Contents

Changelog

2026.02.12.0 Aaron Lawson et al. — Initial published version.

1   Introduction

Much of the background knowledge of this monitoring program including initial motivation, Starlink satellite information, theoretical estimates, initial results, and even installed UT coordinates are available in EVLA Memos 222 and 223. Here we will only reiterate aspects of the program that are critical for understanding.

The Alamo Navajo Reservation is located approximately 24 miles North-East of the center of the VLA. From March 18, 2022 to June 27, 2022, 59 UTs were installed at family residences within the reservation. These UTs are designed to operate in two main modes: uplink and downlink. The uplinks are transmitted from the UTs between 14.0-14.5 GHz, broken up into eight 62.5 MHz channels. The downlinks are recieved by the UTs from the satellite constellation between 10.7-12.7 GHz, broken up into eight 250 MHz channels. Throughout the study, the VLA Ku-band and X-band receivers were used to take data in these frequency ranges.

The X-band observations used two 1 GHz wide basebands centered at 10.7 GHz and 11.7 GHz. Each baseband was made up of eight 128 MHz spectral windows with dual polarization, set so their bounds closely matched the known Starlink channel's bounds. Starlink downlink signals are known to be right circularly polarized. The integration time used was one second. This correlator setup provided coverage of the first six Starlink downlink channels. Tables 1 and 2 provide a detailed description of the uplink and downlink channels and associated VLA spectral windows from these tests.

The Ku-band observations used two 1 GHz wide basebands centered on 12.33 GHz and 14.25 GHz. Each baseband was made up of eight 128 MHz spectral windows with dual polarization. The integration time used was one second. The 12.33 GHz centered baseband provided coverage of Starlink downlink channels 6-8, and the 14.25 GHz centered baseband covered all uplink channels (located between 14.0-14.5 GHz). Each set of spectral windows were set so their bounds closely matched the known Starlink channel bounds.

Starlink DL Channel	Frequency Range (GHz)	Spectral Window ID	Frequency Range (GHz)
1	10.700-10.950	30	10.700-10.828
		31	10.828-10.956
2	10.950-11.200	32	10.956-11.084
		33	11.084-11.212
3	11.200-11.450	18	11.188-11.316
		19	11.316-11.444
4	11.450-11.700	20	11.444-11.572
		21	11.572-11.700
5	11.700-11.950	22	11.700-11.828
		23	11.828-11.956
6	11.950-12.200	24	11.956-12.084
		25	12.084-12.212
7	12.200-12.450	13	12.202-12.330
		14	12.330-12.458
8	12.450-12.700	15	12.458-12.586
		16	12.586-12.714

Table 1: Shows a breakdown of Starlink's downlink system (and channelization) and how it was mapped to the VLA observational correlator setup.

Starlink UL Channel	Frequency Range (GHz)	Spectral Window ID	Frequency Range (GHz)
1	14.0000-14.0625	4	13.994-14.122
2	14.0625-14.1250		
3	14.1250-14.1875	5	14.122-14.250
4	14.1875-14.2500		
5	14.2500-14.3125	6	14.250-14.378
6	14.3125-14.3750		
7	14.3750-14.4375	7	14.378-14.506
8	14.4375-14.5000		

Table 2: Shows a breakdown of Starlink's uplink system (and channelization) and how it was mapped to the VLA observational correlator setup.

Depending on the time of year, the observations were set up to observe either 3C286 or 3C48 for calibration and then slew to an offset nearby area of sky containing only a few weak radio sources. The offset sources were observed for a total of 10 minutes in both uplink and downlink bands.

- Seasonal Strategy A

    - Calibrator: 3C286
    - Nearby Offset Position: 12h39m36.868s, $+30°57'48.790$"

- Seasonal Strategy B

    - Calibrator: 3C48
    - Nearby Offset Position: 0h59m35.811s, $+34°32'57.020$"

From the start of the project (Spring 2022, as the first units were being installed) until mid 2024, the observations were conducted approximately once per month. After this first 2 year period, given the apparent lack of strong RFI impact, the cadence of observations slowed to once per configuration.

Each dataset was reduced using the VLA Calibration Pipeline (with the removal of the Hanning Smoothing task) and then imaged with the CASA `tclean` task. Depending on the VLA configuration at the time of observation, the cell parameter of the `tclean` call was changed so that 3-5 pixels would be present across the synthesized beam, following best practice. The images were then accessed with CASA's `imstat` task and several statistics of interest were extracted and recorded.

Using the VLA's Exposure Calculator Tool we can estimate the expected noise of our images to be about $\sim 12\mu$Jy/beam for the uplink images (14.0-14.5 GHz) and $\sim 9\mu$Jy/beam for the downlink images (10.7-12.7 GHz).

2 Results

As of the publication of this NRAO memo, the long-term monitoring project has conducted $\sim$40 observations. Examples of the images produced by these observations are shown below in Figures 1 and 2.
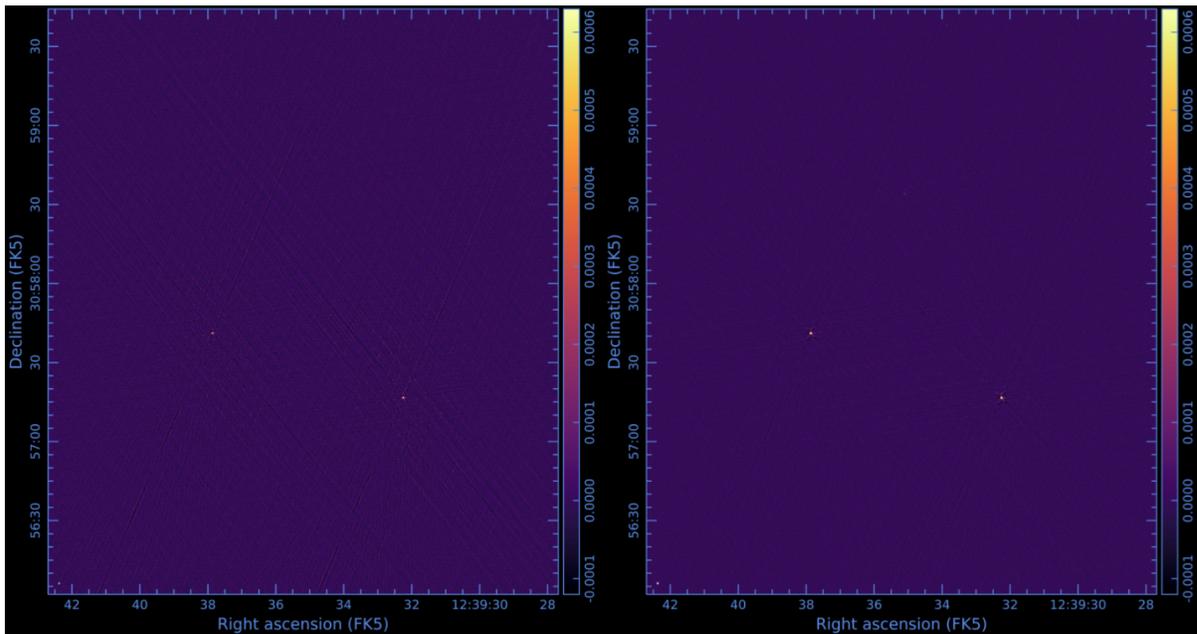
Figure 1: Examples of uplink (left) and downlink (right) images of the Offset sources near 3C286.
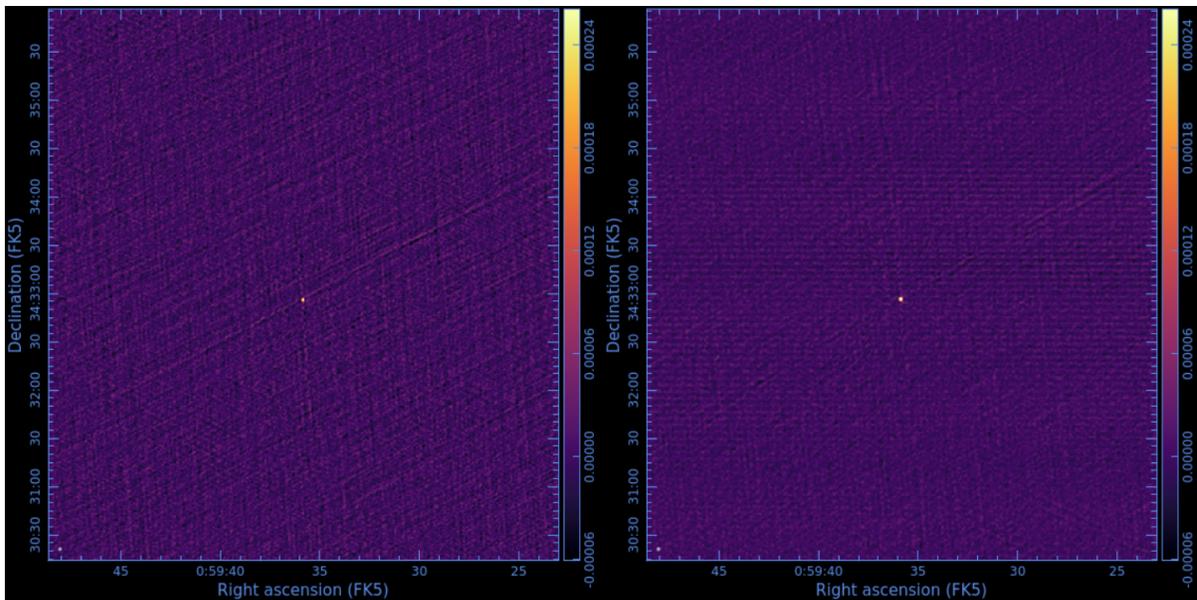

Figure 2: Examples of uplink (left) and downlink (right) images of the Offset sources near 3C48.

Using CASA's `imstat` task as described above, we have extracted RMS values from the ~40 images to produce image RMS vs time plots to track the data quality.
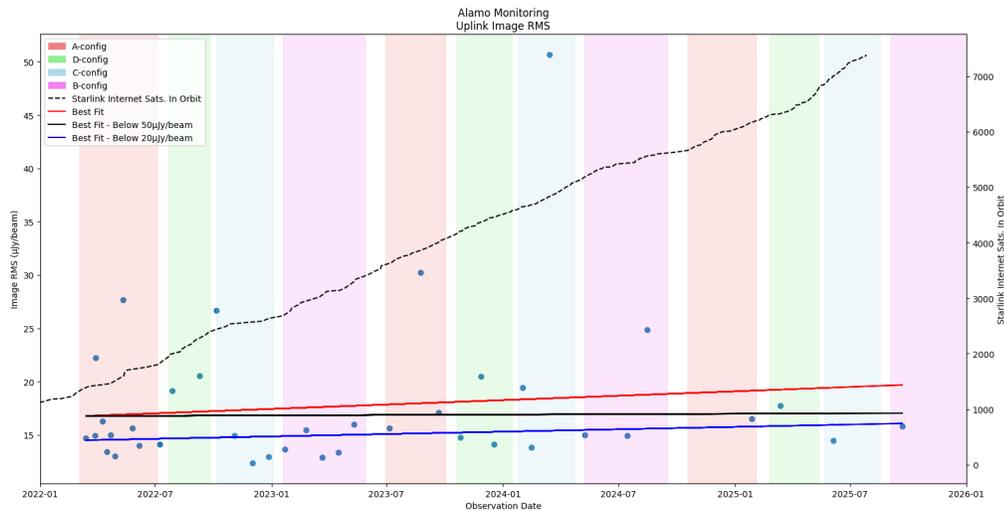
2.1 Uplinks

Figure 3: Scatter plot showing the Image RMS vs Time for the uplink frequencies (14.0-14.5 GHz). Theoretical RMS level calculated to be $\sim 12\mu$Jy/beam. Color shaded regions have been added to show the VLA's configuration schedule. The black dashed line shows the increase in the number of Starlink satellites capable of providing internet service in orbit. We note that by late 2025, this number was over 7000 and has continued to grow

Figure 3 shows the measured RMS values per observation as a function of time. The measured RMS value at uplink frequencies agree with the expected $\sim 12\mu$Jy/beam value. Taking a median of the RMS values in Figure 3 results in a value of $\sim 15\mu$Jy/beam, slightly above the expected theoretical noise value.

While most of the distribution lies around $\sim 15\mu$Jy/beam there are several outlier points. A particularly strong outlier is noticed in the middle of the 2024 C-configuration. That observation was taken during a snow day at the VLA, and the high RMS value is therefore assumed to be due to the poor local weather conditions instead of a result of RFI from the Starlink system. A few other relatively high RMS values ($> 20\mu$Jy/beam) are noted. However, several of these observations did not seem to have operator logs available that could have explained any possible weather impacts. Of the logs that were available, several mentioned weather conditions that would likely coincide with larger RMS values (e.g., rain).

2.2 Downlinks

Figures 4 and 5 show similar plots for observations at the downlink frequencies of the Starlink system (10.7-12.7 GHz).
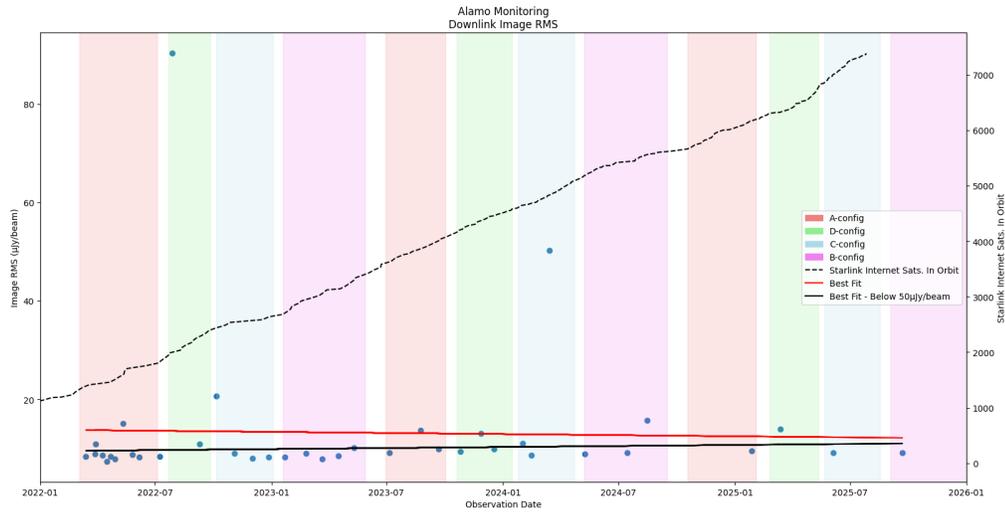
Figure 4: Scatter plot showing the Image RMS vs Time for the downlink frequencies (10.7-12.7 GHz). Theoretical RMS level calculated to be $\sim 9\mu$Jy/beam. Color shaded regions have been added to show the VLA's configuration schedule. Dashed line shows the increase in the number of Starlink satellites capable of providing internet service in orbit.
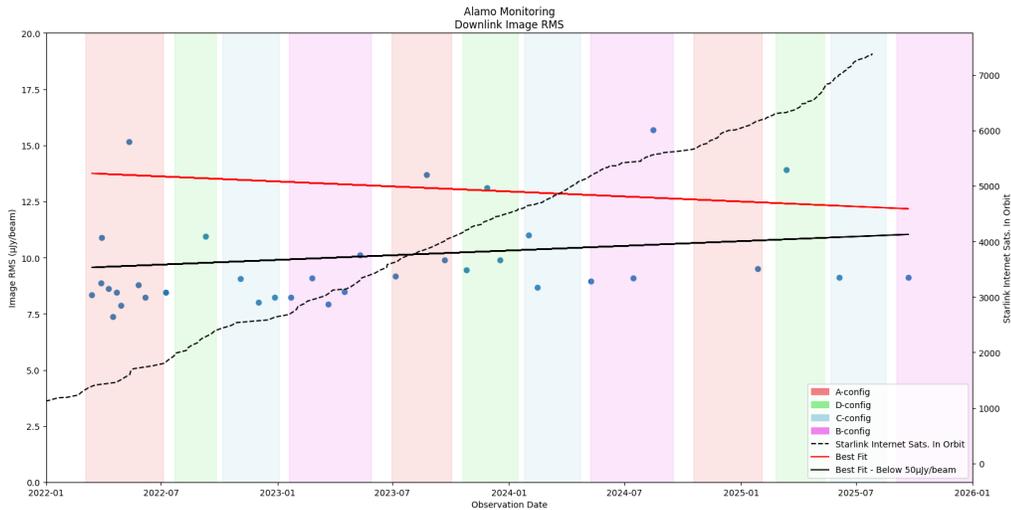

Figure 5: Same data as Figure 4, but with the 3 largest outliers removed to more clearly show the majority of the points. Theoretical RMS level calculated to be $\sim 9\mu$Jy/beam. Color shaded regions have been added to show the VLA's configuration schedule. Dashed line shows the increase in the number of Starlink satellites capable of providing internet service in orbit.

Measured RMS values for the downlinks also tend to agree well with the expected $\sim 9\mu$Jy/beam value and taking a median of the RMS values in Figure 5 results in a value of $\sim 9\mu$Jy/beam.

Again, while the median value is consistent with the expected theoretical noise there were a few outliers during the span of data taken. In Figure 5 an extreme outlier can be seen during the 2022 D-configuration. The visibility data from the pipeline was checked for this data set and the high RMS value was determined to be due to unrealistically high data weights affecting the imaging process (an effect often found in VLA pipeline processed data that results from the CASA `statwt` task working on erroneously low data amplitudes). The 2024 C-configuration outlier from Figure 4 in the Uplink section, thought to be from snowy weather conditions, appears again here.

3 Conclusion

Neither the Uplink or Downlink images seem to show a significant change in RMS with time, despite the fact that Starlink has launched in excess of 7000 satellites during this time (see dashed black line in Figs. 3-5). In fact, since the start of the monitoring project the number of Starlink satellites in orbit capable of providing internet service has increased sevenfold, whereas the data quality level, as measured by image RMS, has largely remained flat. Additionally, from talking with SpaceX and local community members (Alamo Navajo Reservation, Magdalena, etc.) we also know the number of UTs in the area has increased beyond those installed as part of this project. We point out that during this experiment, NRAO's Operational Data Sharing (ODS[1]) software became fully operational (August 15, 2024 for VLA X-band and Ku-band) and that ODS has been shown to be particularly effective in reducing system noise at lower frequencies (e.g. 1990-1995 MHz) (Nhan et al., 2025). This result will be discussed in a separate memo.

We conclude that the Starlink internet service (10.7-12.7 GHz downlinks and 14.0-14.5 GHz uplinks) is currently having minimal effect on the VLA imaging performance with standard pipeline data calibration and imaging. The VLA will continue to monitor the internet service band for degraded data quality on a once per configuration cadence.

4 Acknowledgments

References

De Pree, Chris et al. (2023a). *EVLA Memo 222 - Coordinated Starlink User Terminal Testing Near the VLA*. Tech. rep. National Radio Astronomy Observatory. URL: https://library.nrao.edu/public/memos/evla/EVLAM_222.pdf.

— (2023b). *EVLA Memo 223 - SpaceX-VLA Alamo Pilot Testing*. Tech. rep. National Radio Astronomy Observatory. URL: https://library.nrao.edu/public/memos/evla/EVLAM_223.pdf.

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[1]https://obs.vla.nrao.edu/ods/
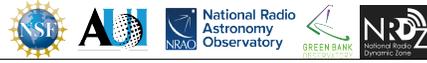
Nhan, Bang D. et al. (2025). "ODS: A Self-Reporting System for Radio Telescopes to Coexist with Adaptive Satellite Constellations". In: *IEEE Communications Magazine* 63.11, pp. 146–151. DOI: 10.1109/MCOM.001.2500125.