Starlink's Supplemental Coverage from Space (SCS) Test at L-Band

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Abstract

As part of the ongoing tests to facilitate spectrum compatibility between satellite internet providers and the radio astronomy community, NRAO's Electromagnetic Spectrum Management (ESM) group, funded by the US National Science Foundation (NSF)'s Spectrum Innovation Initiative - National Radio Dynamic Zone (SII-NRDZ) grant, has been performing coordinated tests with SpaceX (Starlink). These tests have been performed with the Very Large Array (VLA) and Green Bank Telescope (GBT) at X-Band and L-Band. In this memo, we describe the first coordinated test (SCS-T01-GBT) investigating the effects of Starlink's Supplemental Coverage from Space (SCS) Direct to Cell (DtC) downlinks between 1990-1995 MHz in L-Band data on the GBT. For internal reference, this memo is for the SCS-T01-GBT and SCS-T04-GBT tests.

Contents

Changelog

316.0 Bautista et al. (2025-03-12) — Initial published version.

1 Introduction

In early 2024, the Federal Communications Commission (FCC) authorized SpaceX to engage in testing of the use of the 1990-1995 MHz band for space-Earth transmissions in the continental US. This band is normally used for cellular transmissions by T-Mobile. T-Mobile and SpaceX have reached an agreement on the use of this 5 MHz band for space to ground transmissions in such a way as to not impact normal use of this band on the ground (FCC, 2024a; FCC, 2024b). The US National Science Foundation and SpaceX have arranged tests to determine how SpaceX can operate the Direct to Cell (DtC) system without undue impact on sensitive receivers. The plan was to carry out testing of these transmissions as soon as enough capable satellites were in orbit to make testing useful. The first test (SCS-T01-VLA) was performed on the VLA with only three operational SpaceX-SCS satellites observed in March 2024. This first test observation was performed to assess the impact of the Starlink SCS transmissions in the VLA's L-band receiver (covers 1.0 - 2.0 GHz)[1].

A follow up test at the VLA was performed in July 2024 with two separate observation sessions (SCS-T02a-VLA and SCS-T02b-VLA). In both test sessions, the DtC transmissions are visible in the VLA L-Band data. These tests will be described in a separate RFI memo. In the case of the VLA, the downlink frequencies fall well within the passband of the L-band receiver.

2 Observing Setup

At the GBT, the L-Band receiver has a nominal sensitivity range of 1150 - 1730 MHz, placing the SCS transmissions outside of the bandpass sensitivity. To check for any effects across the band, observations were configured in VEGAS Mode 2, giving a useable bandwidth of 1250 MHz. The center frequency was set to 1440 MHz giving an upper bound of useable bandwidth at 2065 MHz. Circular polarization data was recorded with an integration time of 250 ms. Two L-Band tests were performed, on September 5th, 2024 and December 4th 2024. Both tests were performed under this configuration. Due to the telescope being shut down for summer foundation maintenance, the September 5th telescope pointing was locked at an (Az, El) = (187.2012°, 77.8522°). Telescope motion was available for the December 4th test, and a pointing of (Az, El) = (92.19465°, 79.94°) was used.

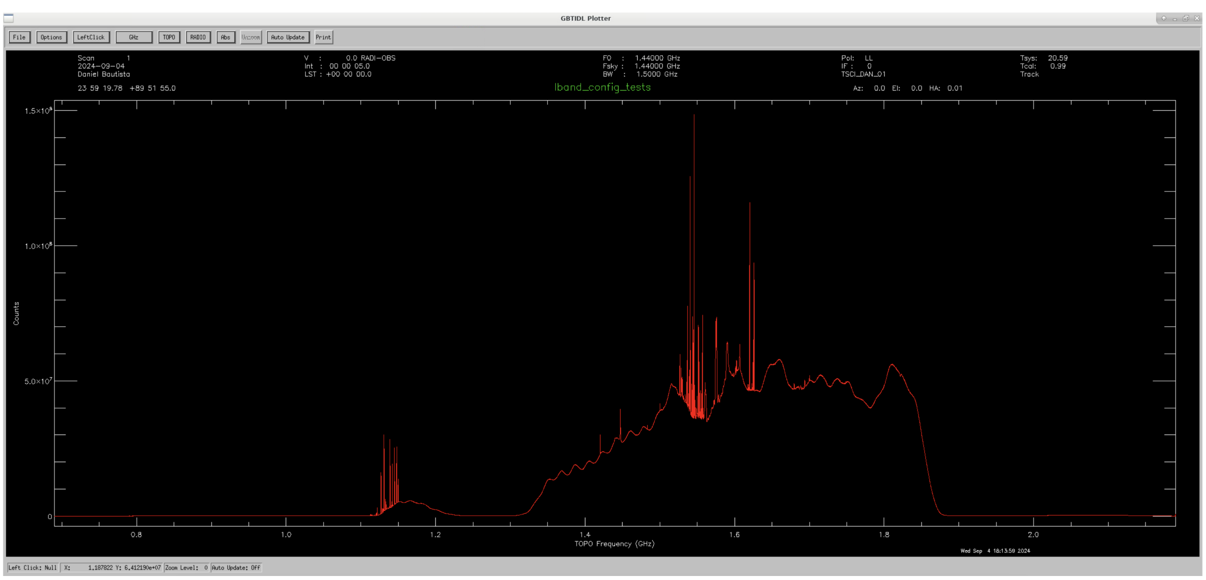

Figure 1: L-Band bandpass.

[1] https://science.nrao.edu/facilities/vla/docs/manuals/oss2016A/performance/bands

Boresight Distance [degrees]	Timestamp (UTC)	Satellite ID	Downlink beam placement distance
21.8336	2024-09-05T18:17:58	11125	150 km
5.0862	2024-09-05T18:25:12	11118	210 km
17.4567	2024-09-05T18:32:35	11111	500 km
30.1732	2024-09-05T18:39:57	11106	150 km
39.9428	2024-09-05T18:47:17	11104	210 km
29.2276	2024-09-05T19:12:23	11127	150 km
13.2926	2024-09-05T19:19:38	11177	210 km
3.7442	2024-09-05T19:27:03	11203	150 km
19.1078	2024-09-05T19:34:24	11210	150 km
31.4742	2024-09-05T19:41:46	11112	210 km
40.9081	2024-09-05T19:49:09	11198	500 km

Table 1: Calculated angular distance of satellite from GBT boresight, SCS transmission times, satellite ID, and downlink beam placement distance from GBT.

3 Data

3.1 September 5th, 2024 Test

3.1.1 Starlink Data

In advance of the GBT L-Band test on September 5th, 2024, SpaceX engineers shared the positions and transmission times of the SCS satellites in the vicinity of the telescope pointing, shown in Table 1. The satellites were scheduled to be placing the main beam of their transmission at estimated distances of 150, 210, and 500 km from the telescope. Thus, none of the transmitting satellites were directly illuminating the telescope. SCS transmission downlink frequencies are 1990-1995 MHz.

3.1.2 Telescope Data

On September 5th 2024, 18:00 - 20:00 UTC, test observations were performed using the L-band receiver. Halfway through the observation (19:07 UTC), the script was resubmitted, which included a rebalance of the IF path attenuation, resulting in the transition in background levels seen in the RR polarization data in Figure 2.

3.2 December 4th, 2024 Test

3.2.1 Starlink Data

SpaceX engineers shared the positions and transmission times of the SCS satellites in the vicinity of the telescope pointing, shown in Table 2. **A major change in this test was that it allowed direct illumination of the site by most satellites, with satellites passing within 10 degrees of telescope boresight being manually overridden by SpaceX operators to not illuminate the site**.

3.2.2 Telescope Data

Test observations were scheduled for December 4th, 2024 at 18:00 - 20:00 UTC. Ongoing maintenance of the telescope prevented observations from beginning at 18:00 UTC, with the first scans beginning at 18:53 UTC.

Boresight Distance [degrees]	Boresight Avoidance	Timestamp (UTC)	Satellite ID
49.45	False	2024-12-04T18:54:38	11348
73.96	False	2024-12-04T18:56:28	11242
67.15	False	2024-12-04T19:02:30	11366
80.68	False	2024-12-04T19:03:42	11271
53.60	False	2024-12-04T19:06:10	11223
75.97	False	2024-12-04T19:09:52	11339
88.51	False	2024-12-04T19:10:52	11248
45.83	False	2024-12-04T19:13:40	11192
86.51	False	2024-12-04T19:16:58	11315
99.38	False	2024-12-04T19:17:54	11273
37.32	False	2024-12-04T19:20:54	11109
100.10	False	2024-12-04T19:23:56	11340
25.57	False	2024-12-04T19:28:08	11115
8.78	True	2024-12-04T19:35:20	11224[a]
52.28	False	2024-12-04T19:42:54	11227
56.11	False	2024-12-04T19:44:02	11208
68.06	False	2024-12-04T19:50:46	11128
74.90	False	2024-12-04T19:58:18	11147

Table 2: Calculated angular distance of satellite from GBT boresight, boresight avoidance state SCS transmission times, satellite ID.

[a] This satellite was predicted to pass close to telescope boresight, and was manually overridden by SpaceX operators to not illuminate the site.

4 Analysis

The waterfall plots in Figures 2 - 5 were produced by subtracting the median spectrum of the entire observation from each subintegration and plotting them increasing in time from bottom to top. For each of the provided downlink times, we see no signs of transmissions within the SCS band. There are signs of in-band RFI spanning the spectrum, but none that correlate with the transmission times and frequencies of the SCS downlink.

Figure 2 is annotated with known transmission times (and boresight distances) for particular satellites from the September 5th test. The 19:27 UTC transmission from satellite 11203 was the closest target, both in angular distance from the telescope beam (3.74°), as well as geographic distance from the uplink terminal (150 km). As this transmission was the closest to the GBT, its presence in the data is expected to be the greatest, however, no signal above the background level can be seen in the data.

Figures 3 and 4 are excerpts of the spectrum containing the HI (1400 – 1427 MHz) and OH (1660.6 – 1670.0 MHz) protected bands, respectively. There is no sign of out of band emission associated with the close to boresight passes within the protected bands.

Figure 5 contains data from the December 4th test and is also annotated with transmission times and boresight distances. The 19:35 UTC transmissions from satellite 11224 passed the closest to the GBT's boresight, with an angular separation of 8.78°, which triggered the boresight avoidance. The next closest satellite to boresight (satellite 11115) had an angular separation of 25.57°, which did not trigger boresight avoidance. In both cases, there was no evidence of the SCS transmissions above the baseline noise level.

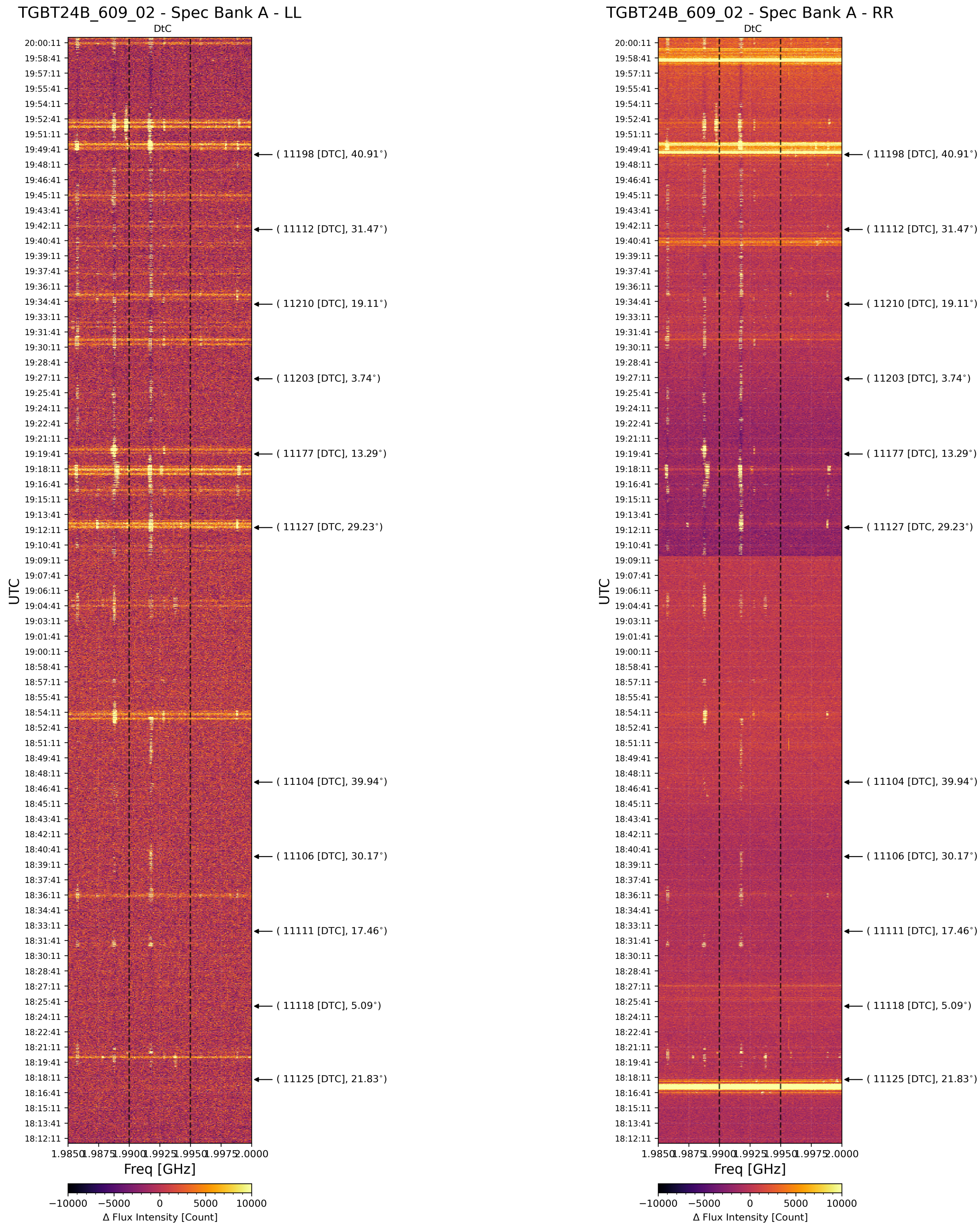

Figure 2: Excerpt of the September 5th, 2024 L-Band waterfall plot of relative raw flux level (in the unit of counts) for the entire observation session in both left (LL) and right (RR) circular polarization are shown. The bandpass with the SCS transmission range (1990-1995 MHz) is indicated with vertical dashed lines. The arrows to the right margin of each panel mark the expected timestamps, Starlink ID, and angular distance from the GBT's boresight, which were computed from the SpaceX provided positions on the sky. The horizontal stripes of higher intensity spanning the entire plot are due to strong, non-SpaceX, RFI coming from within the sensitive part of the bandpass.

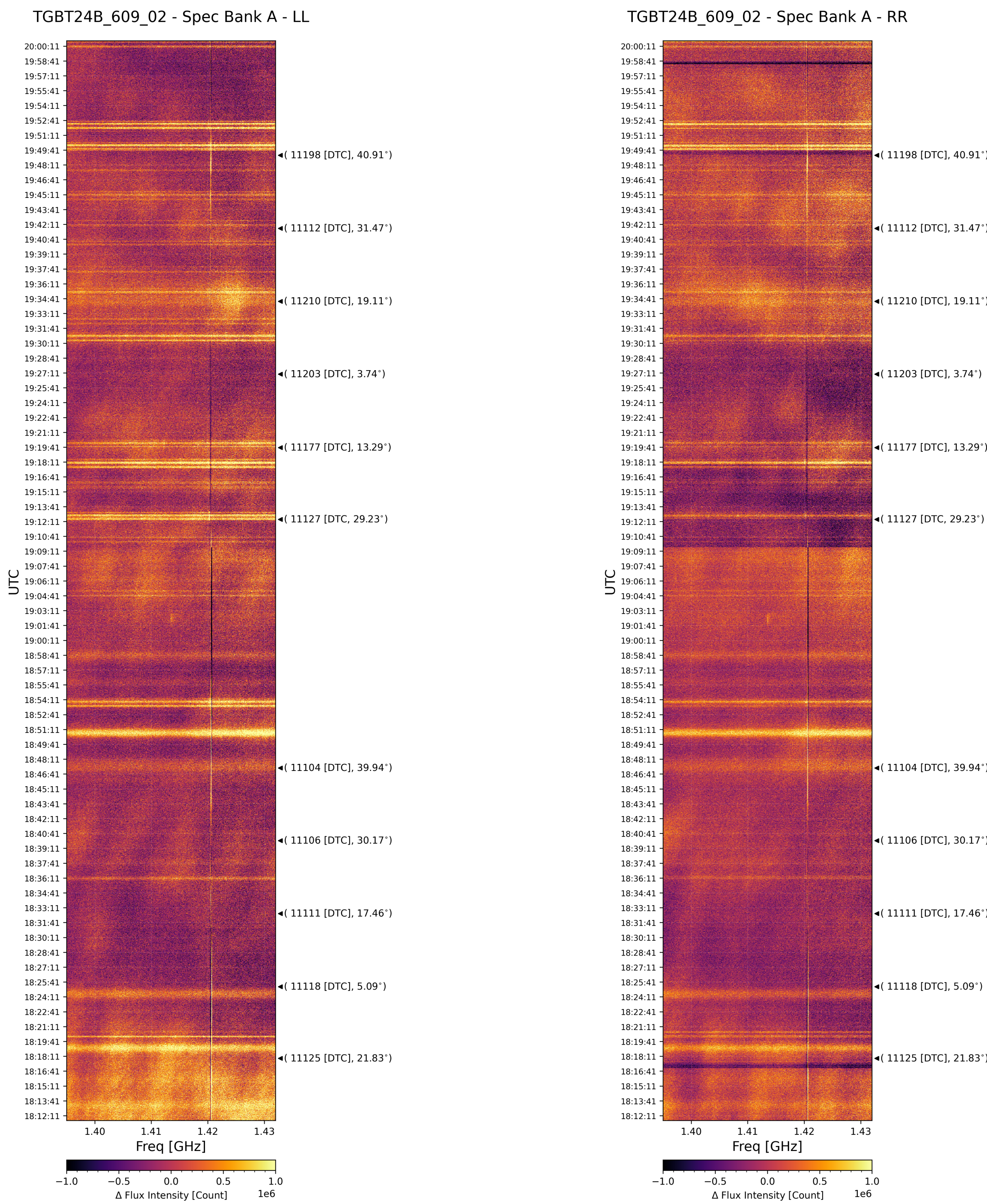

Figure 3: Excerpt of the September 5th, 2024 L-Band waterfall plot of relative raw flux level (in the unit of counts) for the entire observation session in both left (LL) and right (RR) circular polarization are shown. The frequency range covers the HI protected band (1400 – 1427 MHz). The arrows to the right margin of each panel mark the expected timestamps, Starlink ID, and angular distance from the GBT's boresight, which were computed from the SpaceX provided positions on the sky. The horizontal stripes of higher intensity spanning the entire plot are due to strong, non-SpaceX, RFI coming from within the sensitive part of the bandpass.

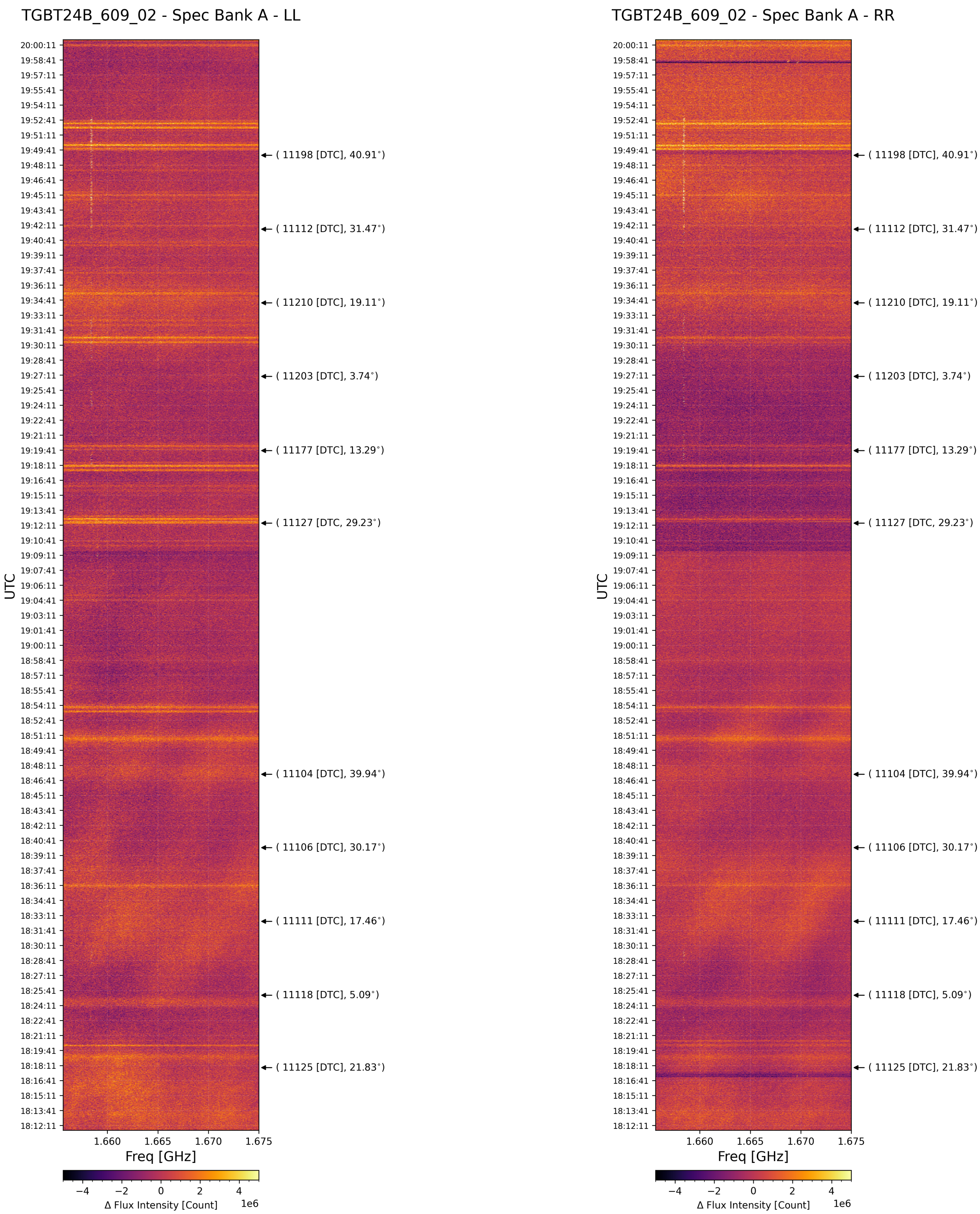

Figure 4: Excerpt of the September 5th, 2024 L-Band waterfall plot of relative raw flux level (in the unit of counts) for the entire observation session in both left (LL) and right (RR) circular polarization are shown. The frequency range covers the OH protected band (1660.6 – 1670.0 MHz). The arrows to the right margin of each panel mark the expected timestamps, Starlink ID, and angular distance from the GBT's boresight, which were computed from the SpaceX provided positions on the sky. The horizontal stripes of higher intensity spanning the entire plot are due to strong, non-SpaceX, RFI coming from within the sensitive part of the bandpass.

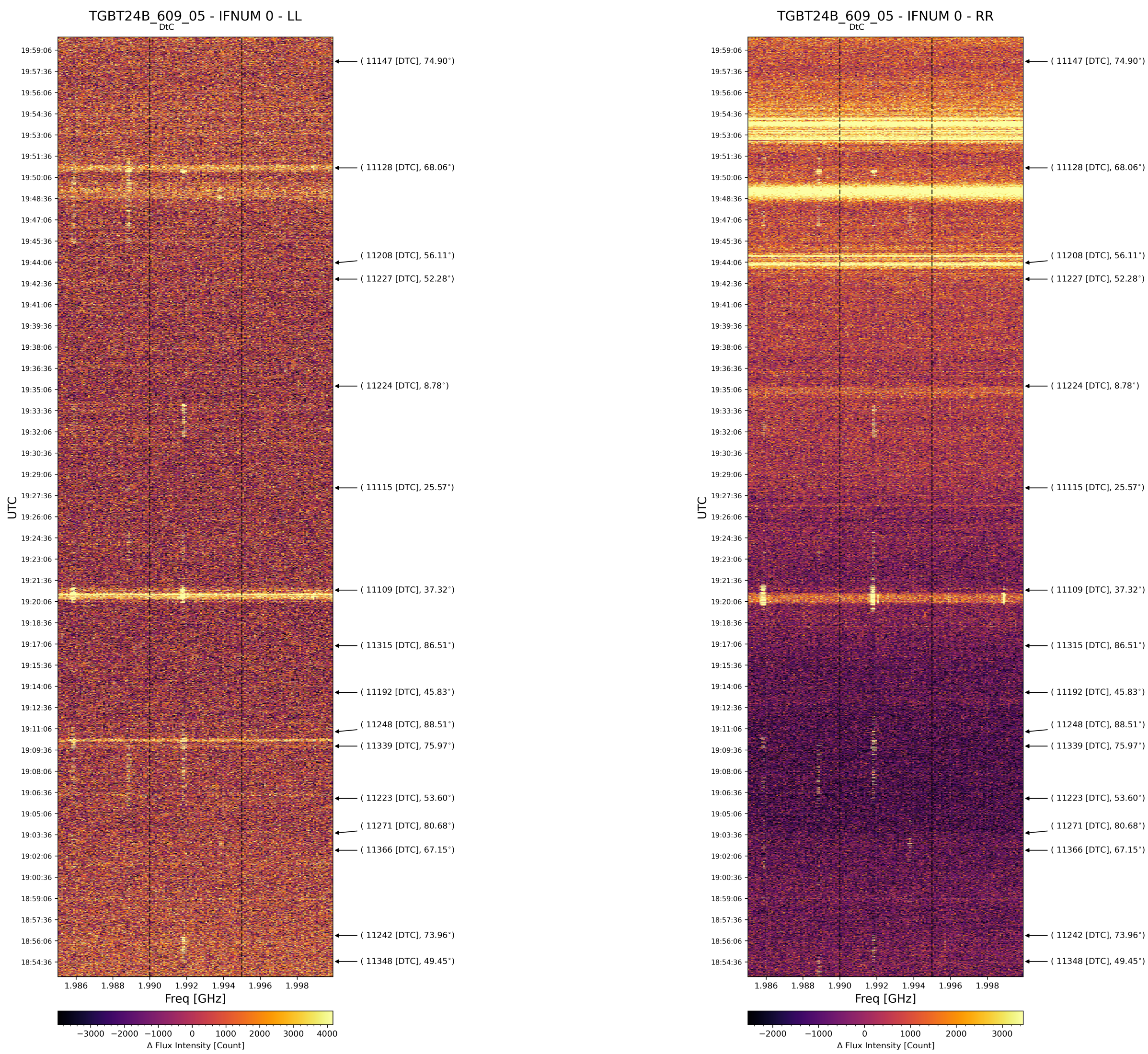

Figure 5: Excerpt of the December 4th, 2024 L-Band waterfall plot of relative raw flux level (in the unit of counts) for the entire observation session in both left (LL) and right (RR) circular polarization are shown. The bandpass with the SCS transmission range (1990-1995 MHz) is indicated with vertical dashed lines. The arrows to the right margin of each panel mark the expected timestamps, Starlink ID, and angular distance from the GBT's boresight, which were computed from the SpaceX provided positions on the sky. The horizontal stripes of higher intensity spanning the entire plot are due to strong, non-SpaceX, RFI coming from within the sensitive part of the bandpass.

5 Conclusions

This test verified the assumption that the GBT L-Band receiver is currently safe from SCS transmissions at 1990-1995 MHz from the Starlink satellites as long as the transmitting satellite is no closer than 10 degrees from boresight. Further testing is required to determine impacts of satellites closer than 10 degrees. No apparent out-of-band emissions (OOBE) were observed in this test. The transmission frequencies are well above the roll off in instrument sensitivity and no SCS signals are detectable above the noise level. Meanwhile, follow-up SCS tests were conducted on September 9th, 2024 for the GBT's S-Band (1.73-2.60 GHz) and November 18th, 2024 for the GBT's Ultra Wideband Receiver (UWBR, 0.7-4.0 GHz) (which are described in a separate memo: Crosslisted as GBT memo 317 and RFI memo 160). Nonetheless, it will be prudent for us to redo a similar test within the next 12 months, especially as the number of SCS satellites is increasing. By then, we expect the Operational Data Sharing (ODS) boresight avoidance will be in place for the GBT to provide additional protection for close-to-boresight encounters.

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