LWA-OVRO Memo No. 2

RFI Environment at the OVRO LWA: Quantitative Measurements

Larry D'Addario and Mark Hodges
California Institute of Technology

2019 April 20

Submitted 2020 June 2

To cite this memo in another document, use:
"LWA-OVRO Memo 2, 2019 April 20, http://tauceti.caltech.edu/LWA/lwamemos.html "

RFI Environment at the OVRO LWA: Quantitative Measurements

Larry D'Addario and Mark Hodges
California Institute of Technology
20 April 2019

Abstract— Measurements of the power spectral density of signals received by a few selected OVRO LWA antennas were collected for at least 24 hours over the frequency range 0 to 165 MHz. The objective was to quantify the RFI environment, concentrating primarily on the signals outside the target observing band of 25 to 85 MHz. Those out-of-band signals are subject to suppression by filtering. Significant filtering is practical only after the signals are delivered to the processing shelter, so these results can be used to set the dynamic range requirements for the RF-over-fiber links from outer antennas and for the pre-filtering analog signal processing at the shelter, as well as the amount of filtering needed to keep the signals within the dynamic range of the digitizers. It is found that the total power below 20 MHz (HF communication) is highly variable with peaks about 16 dB above the total power in the observing band, and that the total power above 88 MHz (primarily FM radio) is very stable at about 29 dB above the minimum power in the observing band. Sporadic in-band RFI is also seen.

I. INTRODUCTION

Previous studies of the low-frequency RFI environment at OVRO have also used an LWA antenna [1-2], but they used high-frequency-resolution and high-time-resolution observations in order to identify specific source of interference, rather than concentrating on the total power RFI power as we do here. It is the total power that determines whether non-linearities in the signal path will cause, via intermodulation, RFI from outside the 25-85 MHz observing band to appear inside the band. Out-of-band RFI is subject to mitigation by analog filtering. There is also in-band RFI [3], both sporadic and persistent, which cannot be suppressed by pre-digitization filtering, but its total power is usually much smaller than the desired sky signal, so we can rely post-digitization (digital) filtering with high spectral resolution to isolate it from the desired signal.

The LWA antenna has a decidedly non-flat frequency response [4], so RFI studies that use a different antenna leave some uncertainty about how it will affect the array in practice. The front end electronics (FEE) of each LWA antenna is flat over a wide range. It contains about 37 dB of gain that rolls off slowly below 3 MHz (due to DC blocks and bias tees) and it includes a lowpass filter with –3 dB point at 150 MHz (5th order Butterworth)[4]. The measurements reported here observed the outputs of the FEE at several LWA antennas, and therefore obtained representative measurements of the environment from about 3 MHz to 150 MHz.

It is not practical to include strong filtering at the antenna, and it is not necessary since even the strongest RFI produces signal levels are well below the power capabilities of the FEE amplifiers (our data indicate less than –30 dBm worst case at the FEE output). However, more gain is needed to drive the lasers of the RF-over-fiber links used for the outer antennas, and the lasers themselves have limited dynamic range. Strong filtering is possible in the analog receivers (ARXs) once the signals arrive at the processing shelter. Filtering is needed prior to the digitizers to avoid intermodulation due to digitizer clipping, but providing more filtering than needed can compromise sensitivity at the edges of the desired observing band, 25 to 85 MHz. In an earlier report [5], it was shown that an 8-bit digitizer allows about 20 dB of headroom above the power in the observing band for RFI accommodation, so the filtering must suppress out-of-band RFI below this level.

Thus an understanding of the pre-filtering RFI level is needed to set the requirements on the fiber link dynamic range and on the filters in the ARXs. That is our objective here.

II. SETUP

Antennas 128 and 160, near the southern end of the array, were selected for these tests because they are close to the shelter and thus connected by short cables (35.3 and 37.5 m, respectively, approximately 3.3 dB loss at 100 MHz) and because they are well separated from their nearest-neighbor antennas (> 13m). See Figure 1.

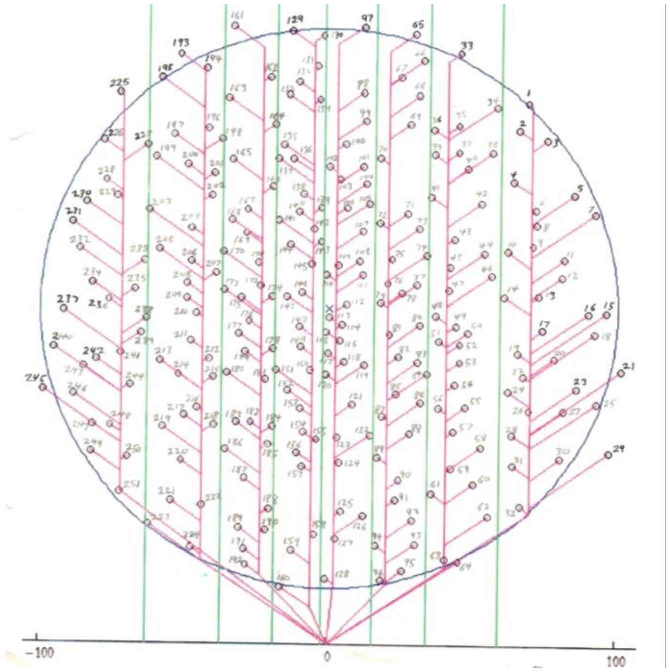


Figure 1. Layout map of the OVRO LWA core. Antennas 128 and 160, near the bottom of the map, were used for these measurements.

The signal from each polarization of each antenna was observed by connecting the setup shown in Figure 2 to the cable termination inside the processing shelter (Type N connector on bulkhead wall). The setup includes a Mini Circuits ZFBT-4R2GW-FT+ bias tee (0.1-4.2 GHz) and ZFL-500LN amplifier (0.5-500 MHz, 28 dB gain, 2.9 dB NF, +8 dBm at –1 dB) ahead of a Anritsu MS2721A spectrum analyzer. The FEE is powered via the bias tee from a laboratory 15V supply, which also powers the ZF2-500LN amplifier.

The spectrum analyzer is controllable over Ethernet using the SCPI protocol. Software was written to support setting up its configuration and for downloading measured traces. For these tests, it was configured to a frequency range of 0 to 165 MHz; a resolution bandwidth (RBW) of 300 kHz; a video bandwidth of 100 Hz; an input attenuation of 10 dB; internal preamp off; detector type "rms"; and a resolution of 551 points per trace. This makes the frequency step equal to the RBW, allowing simple integration to obtain the total power in any desired sub-band. The noise floor of the setup, with respect to the bias tee input, was found to be –84 dBm/RBW.

III. RESULTS

A spectrum analyzer trace was recorded every 15 minutes for periods of at least 24 hours per signal. The observations were done during the following time periods:

- Signal 128A: 2019 Apr 09 at 19:20 to Apr 10 at 03:05 UTC (preliminary setup)

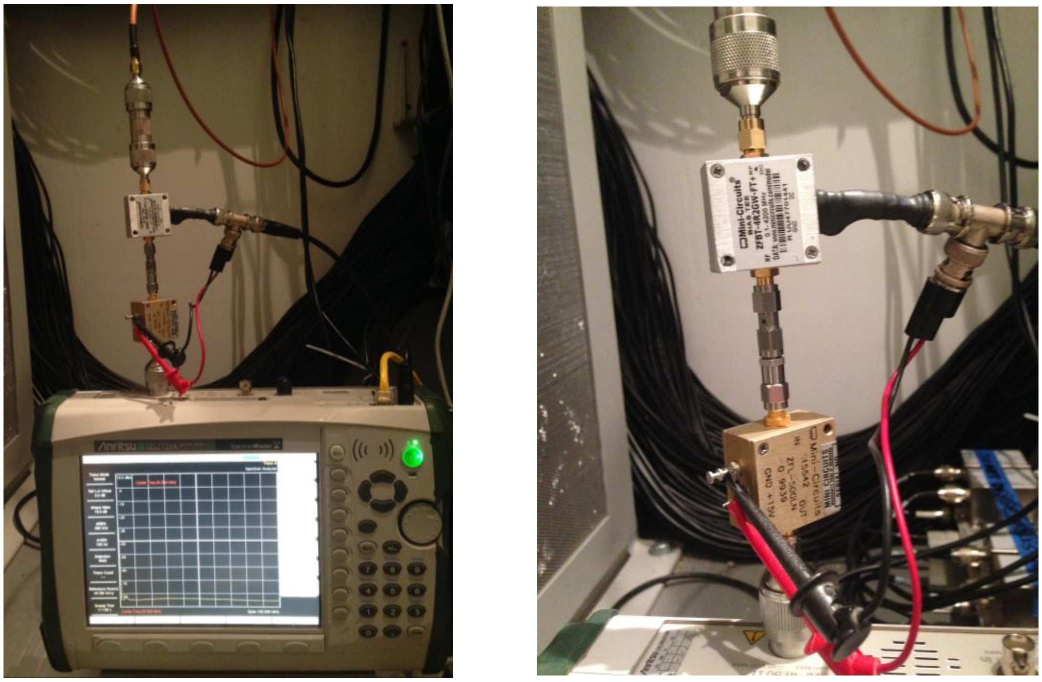


Figure 2. Photographs of the test setup in the processing shelter. *Left:* Cable from the N bulkhead comes in from the top and passes through a bias tee and amplifier before connecting to the input of a spectrum analyzer. *Right:* Close-up of bias tee and amplifier. See text for further details.

and 2019 Apr 10 at 04:38 to Apr 10 at 18:55 UTC.

- Signal 128B: 2019 Apr 10 at 20:39 to Apr 11 at 20:05 UTC.
- Signal 160A: 2019 Apr 11 at 21:10 to Apr 12 at 20:56 UTC.
- Signal 160B: 2019 Apr 13 at 00:02 to Apr 15 at 11:53 UTC

The resulting plots are shown in Figures 3-6. For each of the four signals observed, the results are presented in three plots: the dynamic spectrum as a color-mapped image; all spectra overlayed; and the time series of integrated total power across the 1-20 MHz, 25-85 MHz, and 88-165 MHz subbands.

IV. Discussion

The time series of power in each subband contains the information most relevant to our purpose here. It is immediately apparent from the plots that both the low RFI band and the high RFI band have more total power than the signal band. The high band is much stronger and the power there is generally stable at 26 to 30 dB above the observing band power. Although there is significant power in the 110-165 MHz range, the total power above 88 MHz is strongly dominated by the FM radio band, 88-108 MHz. The low band is highly variable but always stronger than the observing band; the worst case we observed was 19 dB above the minimum observing band power.

The four signals we observed, from two antennas, behaved similarly. There is little evidence of polarization dependence for the aggregate RFI level, although individual horizon sources could appear different because of the gain variation with azimuth. (In the low band, the peak level for both A polarizations was –20 dBm at the spectrum analyzer, whereas the peak level for both B polarizations was –17 dBm, so there might be a weak dependence.) The two antennas are on the southern edge of the array, so the remaining antennas provide some shielding of northern RFI sources; if there are significant sources in those directions, other antennas may see higher RFI levels.

As shown earlier [5], 8-bit digitizers with gains set to provide high SQNR for the observing band can tolerate total RFI power about 20 dB above the observing band power without significant intermodulation from digitizer clipping. This suggests that suppression of high-band RFI by about 10 dB and additional suppression of low-band RFI would be sufficient to avoid splattering of RFI into the observing band. If 10-bit digitizers are used, the tolerance is increased to more than 31 dB, which suggests that no further suppression is needed. This assumes that all processing ahead of the digitizers remains highly linear.

The LWA uses 196.608 MHz sampling, so RFI above 111.608 MHz will be aliased into the 25-85 MHz observing band, even with no intermodulation. The high-band RFI is dominated by steady FM radio signals that are below 108 MHz, but the intermittent higher frequency sources seen in our measurements may need further suppression. Since they are further from the observing band, they are easier to filter; suppression by 30 dB will put the ones we observed at least 10 dB below the sky signal in 300 kHz. Since they are narrow bandwidth, residuals can then be excised by flagging after digital filtering, in the same way as narrow in-band RFI.

In the frequency range 75-85 MHz, our measurements show evidence of intermodulation between the strongest FM radio signal at 92.7 MHz and signals below 20 MHz. This is most apparent in the dynamic spectra. (Thanks to Gregg Hallinan for pointing this out.) This intermodulation is at the difference frequency of two inputs, so it is the result of second-order distortion. This is most likely occurring in the test setup, either in the spectrum analyzer or in the preamplifier, rather than in the front end electronics of the antennas. The largest total power seen was about –6 dBm at the spectrum analyzer, or about –33 dBm at the FEE output. The FEE has an output amplifier (MiniCircuits Gali-6) with a 1 dB compression point of +18.2 dBm and a 3rd-order intercept (IP3) of +35 dBm, so we do not expect any measureable non-linearity. Our preamp has a 1 dB compression point of +7.8 dBm and an IP3 of +14 dBm (measured for sinusoidal signals), so some intermodulation of broad-band signals is possible; there is no specification on second-order distortion[1]. The spectrum analyzer, as set up here, is specified to have a second harmonic response of –70 dBm at –20 dBm input. Since second-order distortion is proportional to the product of the two input levels, the specification corresponds to $(–20\text{dBm})^2 = –40\ \text{dBm}^2$. The worst intermodulation we observed was with inputs of –7 dBm and –20 dBm, or $–27\ \text{dBm}^2$, so we predict an intermodulation product at –57 dBm, but we see products as large as –39 dBm. Thus the spectrum analyzer is probably not the culprit; the preamp is suspected.

REFERENCES

[1] M. Anderson and M. Eastwood, "Owens Valley and Deep Springs RFI Survey." Undated report; file metadata modification date 2014 Feb 3.

[2] A. Janzen, "Owens Valley - Deep Springs RFI Comparison Survey." Caltech EE Dept. report, 2014 Oct 20.

[3] K. Oberberger and J. Dowell, "LWA1 RFI Survey." LWA Memo 183, 2011 Dec 16.

[4] B. Hicks, S. Burns, T. Clarke, *et al.*, "Design of the LWA-1 Array, Antenna, Stand, Front End Electronics, and Ground Screen." LWA internal report, 2009 May 15. (A preliminary version is published as LWA Memo 188, 2009 Feb 20:

---

[1] For most of the measurements reported here, the power supply was inadvertently set at 12.4 V rather than the nominal 15V. Preamp distortion is not specified at the lower voltage, but it is expected to be worse. However, later tests at 15V (not reported here) showed similar evidence of intermodulation.

https://www.faculty.ece.vt.edu/swe/lwa/memo/lwa0188.pdf .)

[5] L. D'Addario, "Effective Dynamic Range of Digitizers in the OVRO-LWA Telescope." OVRO-LWA internal report, 2019 Mar 23.

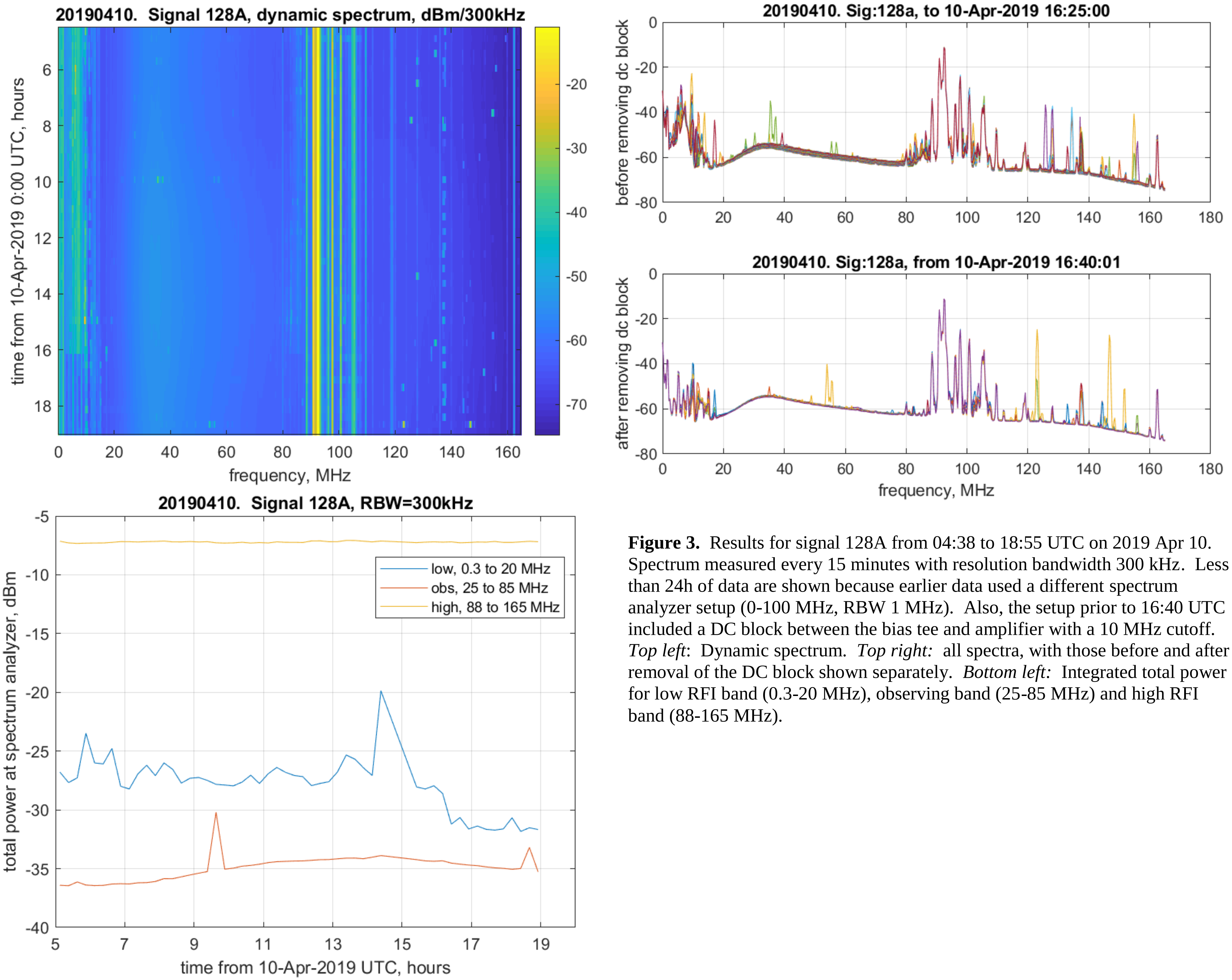


Figure 3. Results for signal 128A from 04:38 to 18:55 UTC on 2019 Apr 10. Spectrum measured every 15 minutes with resolution bandwidth 300 kHz. Less than 24h of data are shown because earlier data used a different spectrum analyzer setup (0-100 MHz, RBW 1 MHz). Also, the setup prior to 16:40 UTC included a DC block between the bias tee and amplifier with a 10 MHz cutoff. *Top left*: Dynamic spectrum. *Top right:* all spectra, with those before and after removal of the DC block shown separately. *Bottom left:* Integrated total power for low RFI band (0.3-20 MHz), observing band (25-85 MHz) and high RFI band (88-165 MHz).

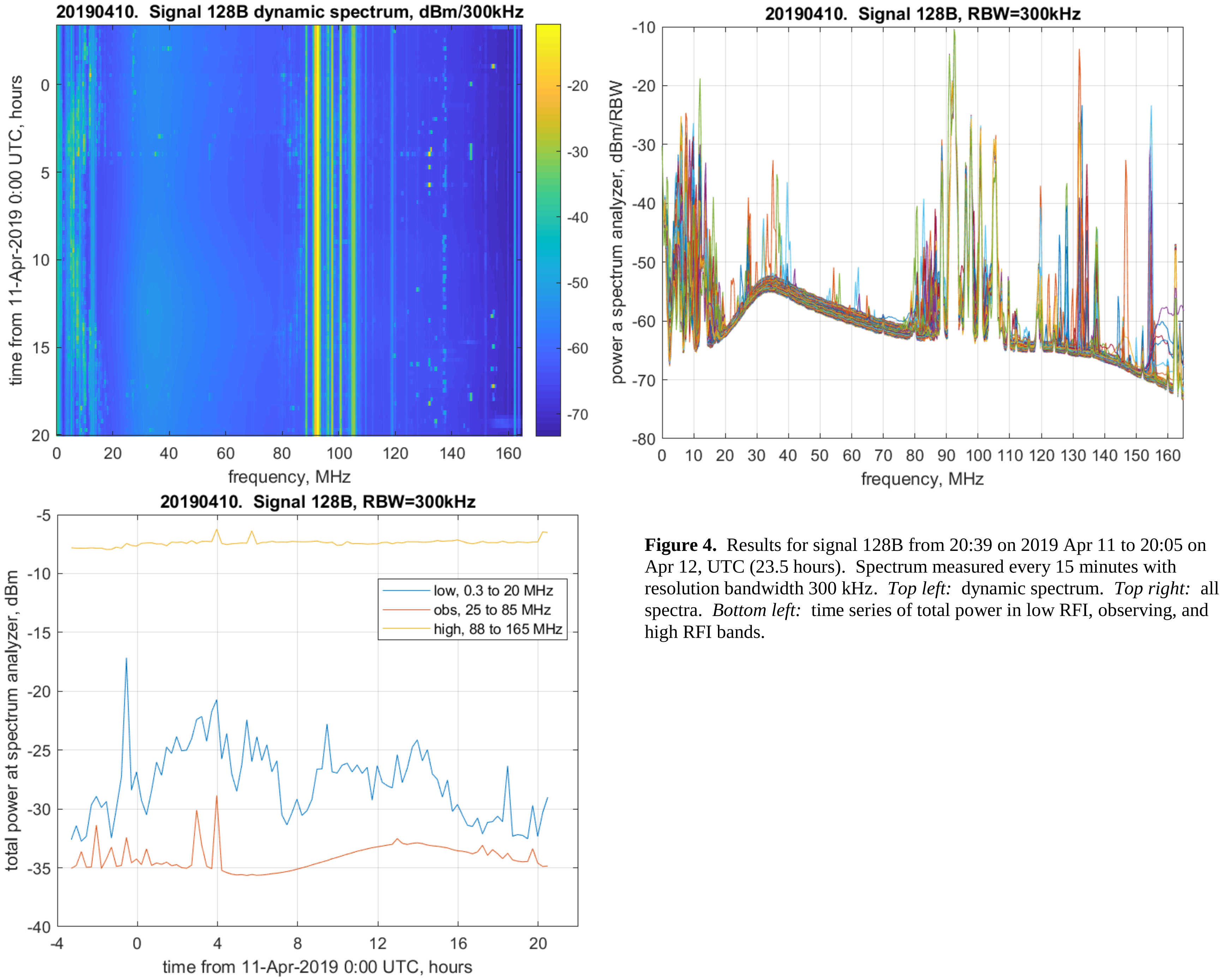


Figure 4. Results for signal 128B from 20:39 on 2019 Apr 11 to 20:05 on Apr 12, UTC (23.5 hours). Spectrum measured every 15 minutes with resolution bandwidth 300 kHz. *Top left:* dynamic spectrum. *Top right:* all spectra. *Bottom left:* time series of total power in low RFI, observing, and high RFI bands.

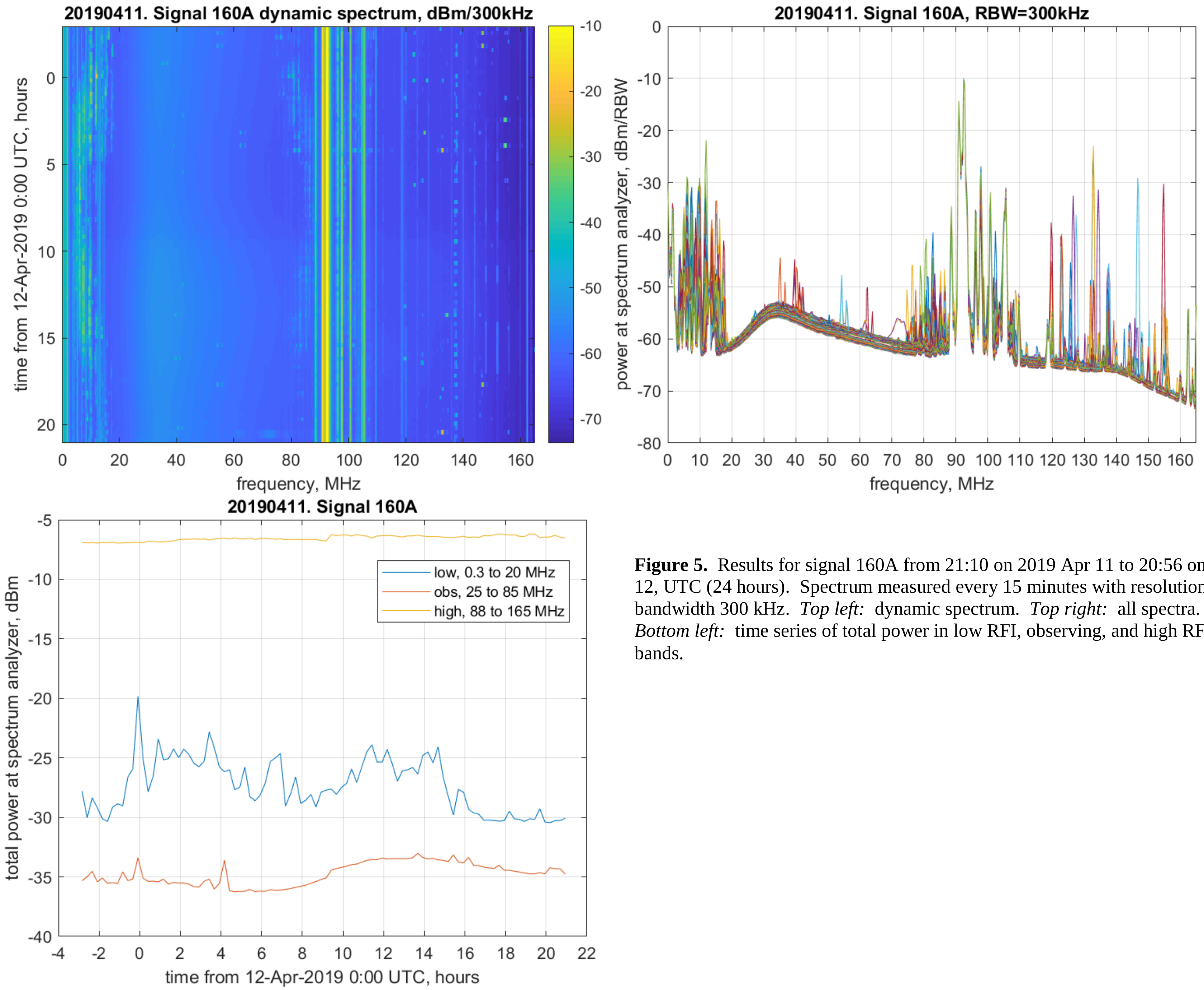
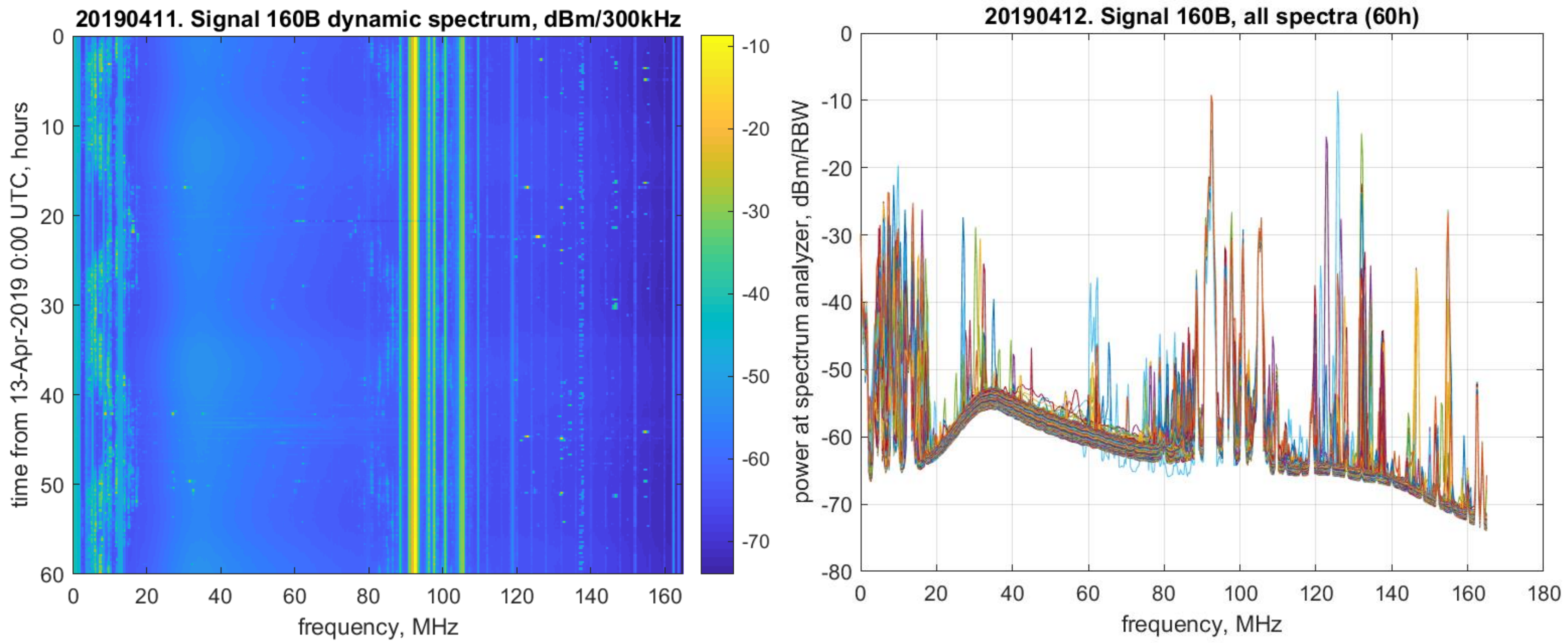


Figure 5. Results for signal 160A from 21:10 on 2019 Apr 11 to 20:56 on Apr 12, UTC (24 hours). Spectrum measured every 15 minutes with resolution bandwidth 300 kHz. *Top left:* dynamic spectrum. *Top right:* all spectra. *Bottom left:* time series of total power in low RFI, observing, and high RFI bands.



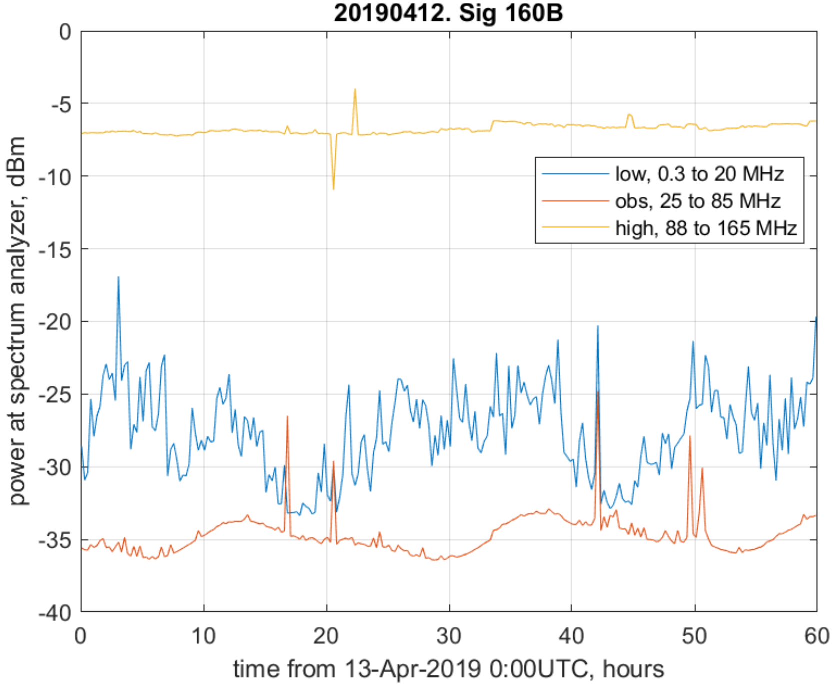


Figure 6. Results for signal 160B from 00:02 on 2019 Apr 13 to 11:53 on Apr 15, UTC. Here we have 60 hours of observations. Spectrum measured every 15 minutes with resolution bandwidth 300 kHz. *Top left:* dynamic spectrum. *Top right:* all spectra. *Bottom left:* time series of total power in low RFI, observing, and high RFI bands.