HAARP – Solar Orbiter Experiment

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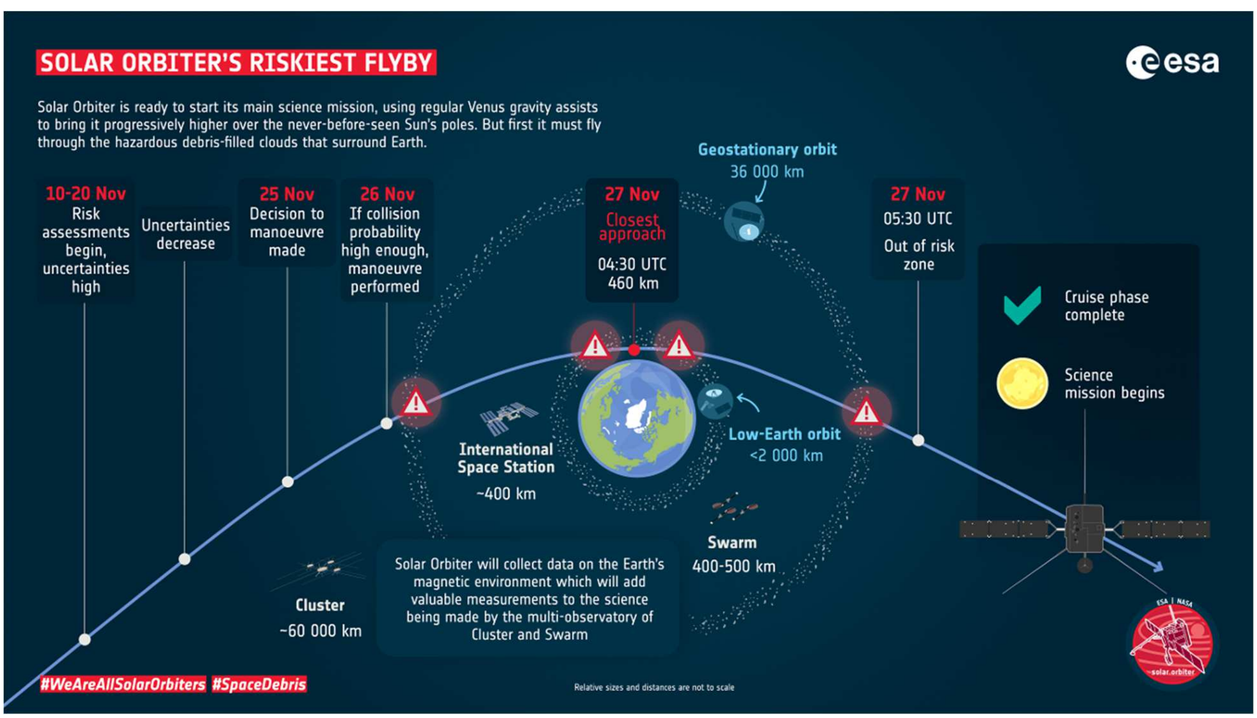
1. Introduction

An experiment was performed on 27 November 2021 during the Solar Orbiter's *Earth Gravity Assist Maneuver (EGAM)*. The EGAM was necessary to place the spacecraft in its required orbit around the Sun after its launch on 10 February 2020. During the maneuver, the HAARP Ionospheric Research Instrument (IRI) transmitted a set of stepped carrier wave frequencies for spacecraft HF receiver calibration. In conjunction with the experiment, I setup two receivers in different places in Alaska to monitor and record the transmissions. I also solicited reception reports from others through the Society of Amateur Radio Astronomers (SARA) email server. This article describes the event in terms of my and three other observations. The spacecraft successfully received the HAARP IRI transmissions but a discussion of those results is beyond the scope of this article.

Solar Orbiter (left, {NASA}) is an international mission operated by European Space Agency (ESA) and NASA that is used to study the Sun and solar system space environment. Solar Orbiter and NASA's Parker Solar Probe work together. Solar Orbiter approached Earth within only 460 km during the EGAM. The maneuver was risky because the spacecraft had to fly through not only active satellite orbits but clouds of space junk (below, {STCE}). The science phase began with the EGAM. The Solar Orbiter is now on course for its close approach to the Sun in March 2022.



During the EGAM, Solar Orbiter entered Earth's shadow for approximately 2 h, at which time the spacecraft's HF receivers were calibrated without interference from solar radio noise. HAARP carrier wave transmissions were programmed to start when the spacecraft emerged from the shadow and was headed back out to space. The closest range to HAARP from the spacecraft at the start of the transmissions was 7 336 km and the farthest range at the end of the transmissions was 76 204 km.

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2. HAARP IRI Setup

The IRI was programmed to transmit linear polarized, unmodulated carrier waves in a specific time-frequency sequence and on specific azimuths and elevations to track the satellite's path (table 1). HAARP uses precision time and frequency supplies, synchronized by the Global Positioning System, to control the transmitters. The start time for transmissions was 0430:30 UTC, 27 November 2021 (0 min), and the elapsed time on each frequency was 9.5 min (carrier ON) with 0.5 min dwell between transmissions (carrier OFF). The total sequence was just under 2 h. For reference, the geographic coordinates of the HAARP IRI are 62° 23' 32.99" N, 145° 09' 2.26" W.

Table 1 ~ HAARP IRI transmission sequence. The IRI cannot transmit below 30° elevation, so it was set to 30° for the three low-elevation steps. Range is to the satellite from the IRI.

Reference (min): Start time (UTC)	**Elapsed time (min): End time (UTC)**	**Frequency (MHz)**	**Elevation (°)**	**Azimuth (°)**	**Range (km)**
0: 0430:30	9.5: 0440:00	2.775	–18 (30)	69	7 336
10: 0440:30	19.5: 0450:00	3.275	17 (30)	115	9 951
20: 0450:30	29.5: 0500:00	4.075	29 (30)	138	15 998
30: 0500:30	39.5: 0510:00	5.775	33	150	22 646
40: 0510:30	49.5: 0520:00	6.775	34	159	29 388
50: 0520:30	59.5: 0530:00	9.575	35	165	36 132
60: 0530:30	69.5: 0540:00	2.775	36	171	42 857
70: 0540:30	79.5: 0550:00	3.275	36	175	49 561
80: 0550:30	89.5: 0600:00	4.075	36	180	56 245
90: 0600:30	99.5: 0610:00	5.775	36	184	62 912
100: 0610:30	109.5: 0620:00	6.775	36	188	69 564
110: 0620:30	119.5: 0630:00	9.575	35	192	76 204

Net transmit power (forward power less reflected power) was approximately 63 dBW (2 MW) except at the band edges (near 2.8 and 10 MHz) where it was lower by about 10 dB. Antenna directivity varied from 19.0 dB at the lower frequencies to 27.6 dB at the higher frequencies, and effective isotropic radiated power (EIRP) varied from 81.8 to 90.0 dBW (151 kW to 1 MW). Examples of the antenna beam patterns show the main beams and sidelobes (figure 1). For additional information and pictures of the HAARP IRI, see {Reeve16}.

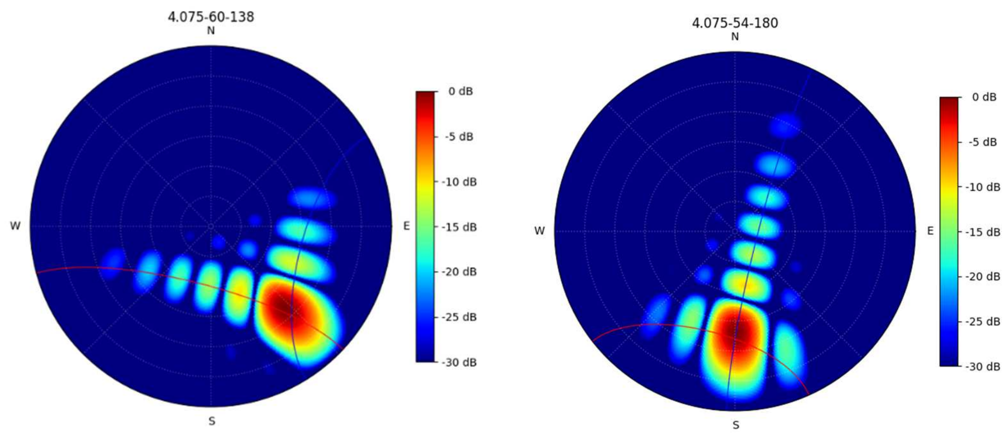

Figure 1 ~ HAARP IRI beam patterns shown in a compass format for the first (left) and second (right) 4.075 MHz transmissions. The text at the top indicates the frequency – zenith angle – azimuth. Note that elevation = 90° - zenith angle. The color graduated scale indicates relative power in the beam. From the transmitter logs for the second specific setup, forward power = 2747.3 kW, reflected power = 916.3 kW, antenna directivity = 21.64 dB and EIRP = 84.27 dBW. These details were computed for each frequency and time period.

3. Instrumentation at Anchorage and Cohoe

This section describes only the instrumentation used at Anchorage Radio Observatory (ARO) and Cohoe Radio Observatory (CRO), both in Alaska. The next section describes the observations at Anchorage and Cohoe and also provides information about the observations and instrumentation used by the other observers to the extent it was provided.

A rotatable 8-element log periodic dipole array with 18-32 MHz design frequency range was used at Anchorage. This antenna is usable over a much wider frequency range. It has a horizontal beamwidth in the neighborhood of 70° in the design frequency range but the beam lobe structure changes significantly outside this range. The antenna azimuth was preset to 107° with respect to true north. An omni-directional LWA Antenna was used at Cohoe. The frequency response of the LWA Antenna is best from about 20 to 100 MHz but this antenna is usable down to around 5 MHz. Its response is very poor below 5 MHz.

The block diagrams show the basic instrumentation setups at Anchorage and Cohoe (figure 2). RFSpace software defined radio (SDR) receivers, CloudSDR and Cloud-IQ, were used at Anchorage and Cohoe, respectively. The receivers were controlled by the SpectraVue software running on local PCs. The receivers were connected to each antenna through a multicoupler or splitter and supported by similar support infrastructure seen in the block diagrams.

Both SDR receivers were setup to monitor and record a relatively narrow frequency range. SpectraVue recorded the In-phase and Quadrature-phase (I/Q) digital output streams produced by the receivers in a 5.0 MHz frequency span. CRO was setup for unattended, automatic operation and was monitored from ARO.

SpectraVue is capable of only five scheduled recording setups. The center frequency is specified in the recording schedule. However, the frequency span must be preset outside of the schedule and will be the same for all recordings (unless manually changed on-the-fly). To accommodate this limitation, I programmed four recordings with a group of three time-frequency steps in each. Each recording setup included the start time for the group of three steps, 30 min duration, and a center frequency of either 4.0 or 8.0 MHz depending on the range of the group. The 4.0 and 8.0 MHz center frequencies combined with a preset 5.0 MHz span covered the frequency ranges of 1.5 to 6.5 MHz and 5.5 to 10.5 MHz. I would have preferred separate timed recording for each time-frequency step, a total of twelve steps, and a much narrower frequency span for each step, but that was not possible with SpectraVue.

The Cloud-IQ FFT frame size is 16 384 bits for a 5.0 MHz frequency span. Its sampling rate was 61 439 970 Hz, which provided a resolution bandwidth of 374 Hz. The CloudSDR is capable of a much larger frame size and in this case it was set to 65 536 bits. Combined with the sampling rate of 61 439 870 Hz, the CloudSDR resolution bandwidth was 94 Hz.

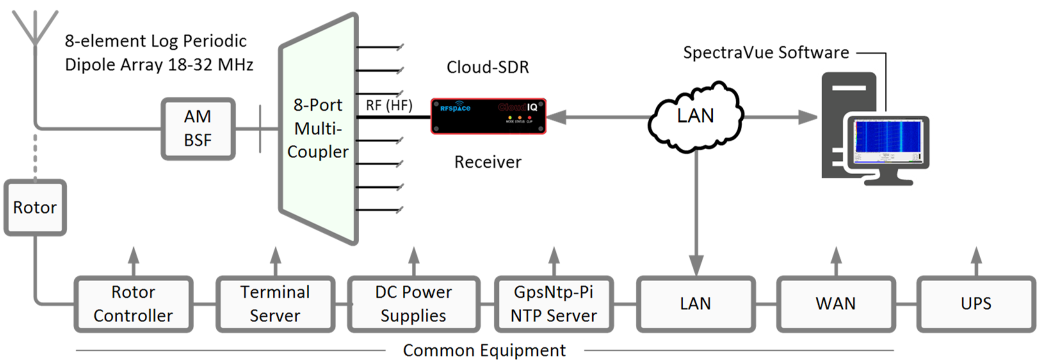

Figure 2.a ~ Anchorage Radio Observatory instrumentation block diagram; only components used in the observations are shown. The Anchorage antenna was previously pointed toward the time-frequency station WWV on 107° true azimuth and left in that position for the HAARP-Solar Orbiter experiment. The true azimuth and distance of the HAARP facility to Anchorage is 241° and 286 km.

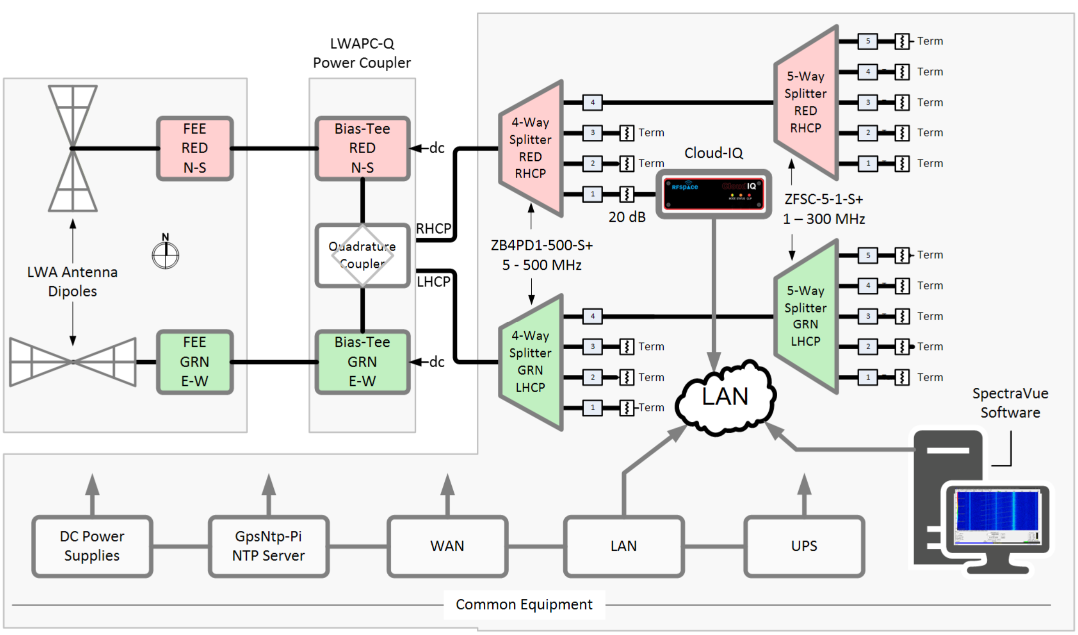

Figure 2.b ~ Cohoe Radio Observatory instrumentation block diagram; only components used in the observations are shown. The Cloud-IQ SDR receiver is connected to an RF power splitter that serves other receivers and spectrometers. The true azimuth and distance from the HAARP facility to Cohoe is 235° and 400 km.

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4. Observations

All reception reports came from the USA and are listed in table 2 and mapped in figure 3. The solar terminator map for 0530 UTC shows the position of the Sun at midpoint of the transmissions (figure 4). The transmissions took place during the Anchorage evening hours from 7:30 pm to 9:30 pm Alaska Daylight Saving Time (DST).

Table 2 ~ Receiver station distances

Location	**Distance from HAARP IRI (km)**
Anchorage, Alaska	286
Cohoe, Alaska	400
Northern California	2995
Northwest Illinois	4196
Wenonah, New Jersey	5164

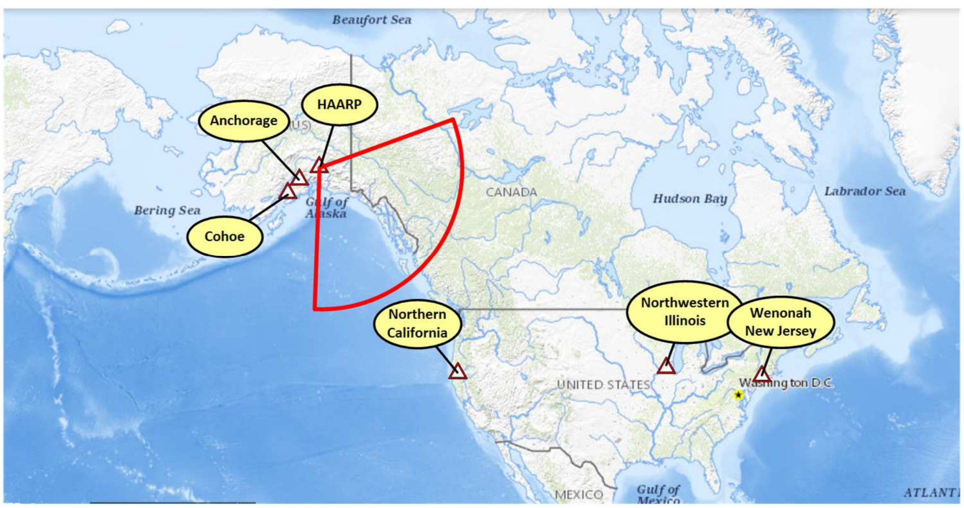

Figure 3 ~ Location map showing sites included in this report. The red arc shows the range of azimuths for the HAARP IRI transmissions. Underlying image source: USGS

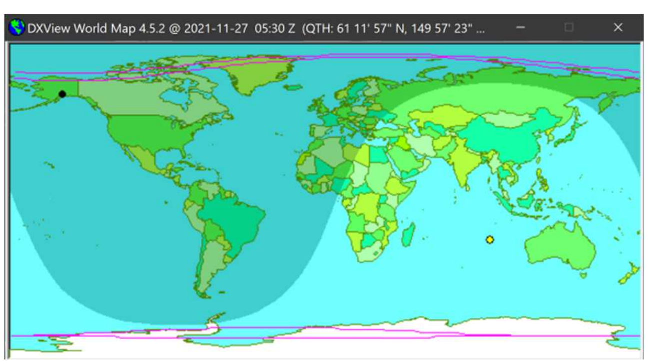

Figure 4 ~ Solar terminator map at 0530 UTC on 27 November 2021. The Sun is the small yellow circle off the Australia west coast. HAARP, ARO and CRO are in the upper-left corner.

Southcentral Alaska:

All frequencies except those below 4 MHz were received at the Cohoe Radio Observatory, as limited by the antenna response (table 3). On the other hand, the antenna at Anchorage Radio Observatory has much better response below 4 MHz and is 100 km closer to the HAARP facility than Cohoe and all frequencies were received there.

The dynamic spectra during the transmissions show the single unmodulated carrier along with radio frequency interference (RFI) at both receiving locations (figure 5). The received signal levels at both locations varied over time due to varying propagation conditions.

Table 3 ~ Anchorage and Cohoe Reception Log
Times in Remarks column are time marks of field notes and are in Alaska DST.

Start time (UTC)	**Frequency (MHz)**	**Anchorage**	**Cohoe**	**Azimuth (°)**	**Remarks**
0430:30	2.775	Yes	No	69	7:36:27 pm
0440:30	3.275	Yes	No	115	7:42:21 pm
0450:30	4.075	Yes	Yes	138	7:52:50, 7:54:41 pm
0500:30	5.775	Yes	Yes	150	8:02:36 pm
0510:30	6.775	Yes	Yes	159	8:13:31 pm
0520:30	9.575	Yes	Higher	165	8:21:05, 8:22:05 pm
0530:30	2.775	?	?	171	No record
0540:30	3.275	?	?	175	No record
0550:30	4.075	Yes	Yes	180	8:53:45 pm, received late???, 8:58:13 pm
0600:30	5.775	Yes	Yes	184	9:01:52 pm, "both locations loud and clear"
0610:30	6.775	Yes	Yes	188	9:12:03 pm, "looking good at both locations"
0620:30	9.575	Very weak	Very weak	192	9:22:51 pm, "short burst of strong signal at Anchorage about 30 seconds after start"

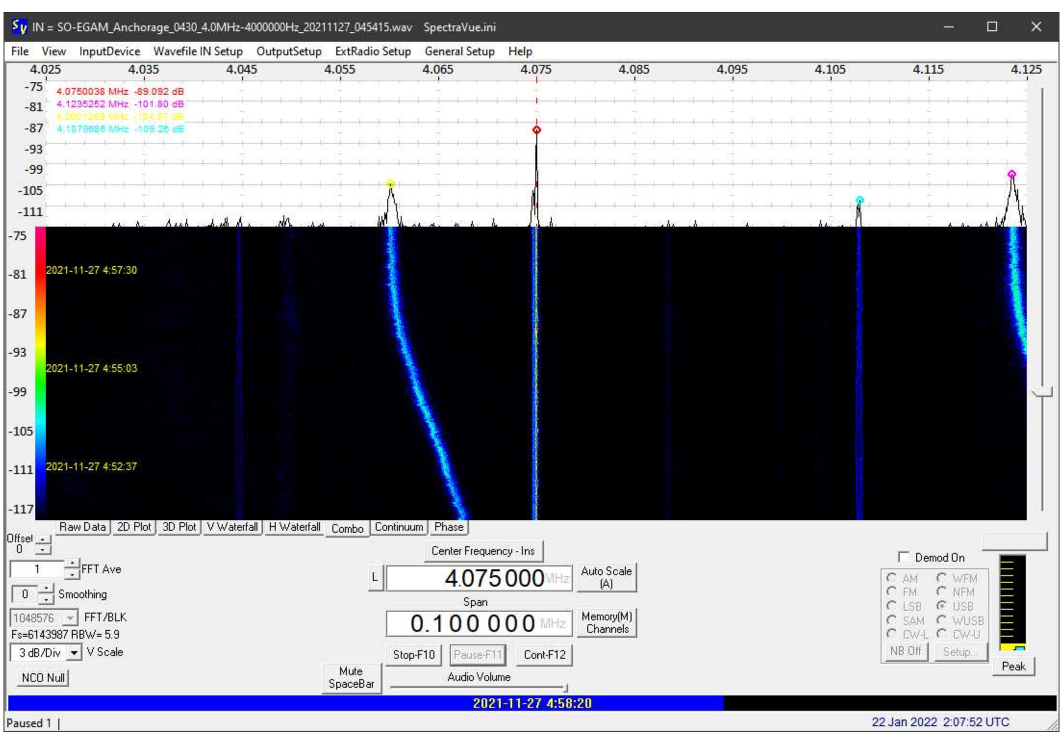

Figure 5.a ~ Spectra and vertical waterfall of the first 4.075 MHz transmission, seen here as the straight, vertical line in center, as received at Anchorage, Alaska between 0450:30 and 0500:00 UTC. The frequency span setting for this view is 100 kHz. Note the RFI drifting through the spectrum from right to left. There also appears to be some narrowband RFI very near the test frequency.

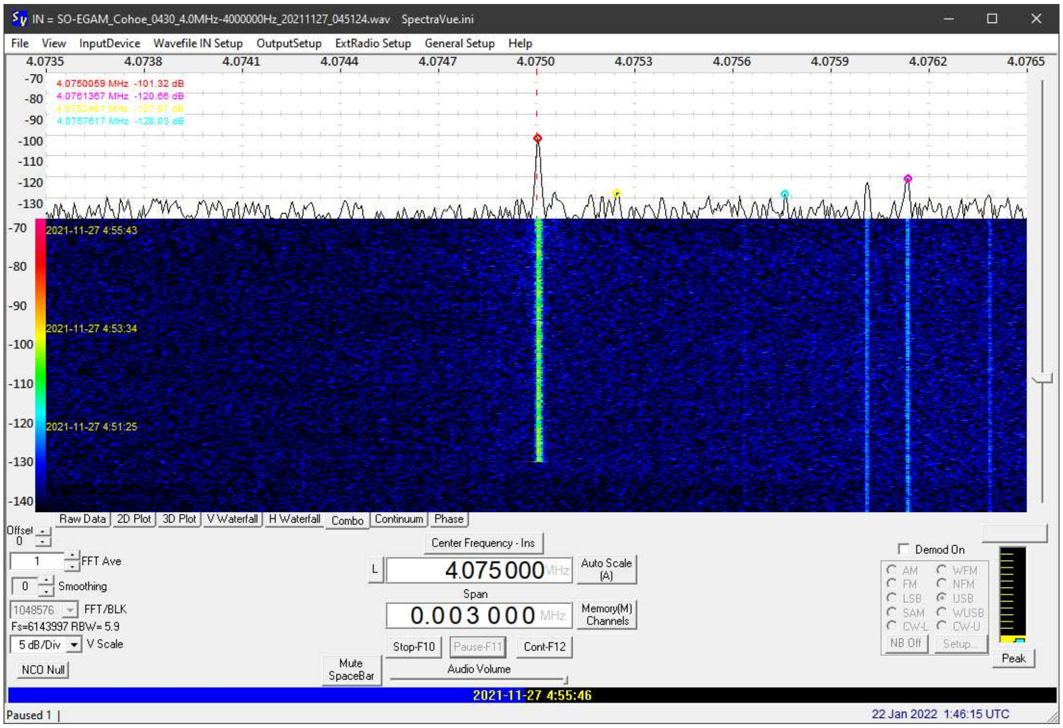

Figure 5.b ~ Spectra and vertical waterfall of the 4.075 MHz transmission received at Cohoe, Alaska starting at 0450:30 UTC, a few minutes before the previous image. The span setting for this view is 3 kHz. Cohoe also was subjected to severe RFI below around 5 MHz, and some of it can be seen between 4.0759 and 4.0765 MHz.

Northern California:

Doug Ronald (radio amateur call sign W6DSR), northern California USA, geographic coordinates 38.950264° N, 123.292075° W, site elevation 2331 ft ASL. The receiver was a Rohde & Schwarz ESH3 Test Receiver with radio amateur band preselection filters. The receiver was at a remote location and it was not possible to bypass the filters, so the filter closest in frequency to the transmission was used. The antenna is a log periodic dipole array (LPDA) with a gain of approximately 7 dBd and a beamwidth of 70°. It was pointed a few degrees off the path. Received signal levels are at the receiver's RF input port (table 4). In summary, all signals were strong at this site on the USA west coast in northern California.

Table 4 ~ Northern California Reception Log from Doug Ronald

Start time (UTC)	Frequency (MHz)	Received signal level at Northern California
0430:30	2.775	–75 dBm (fairly steady amplitude)
0440:30	3.275	–55 dBm (steady amplitude)
0450:30	4.075	Missed due to sumo wrestling highlights on television
0500:30	5.775	–74 dBm (with fades to –94 dBm)
0510:30	6.775	–51 dBm fades to –61 dBm
0520:30	9.575	–92 dBm (steady)
0530:30	2.775	–70 dBm (steady)
0540:30	3.275	–56 dBm (rapid fades to –110 dBm)
0550:30	4.075	–50 dBm (steady amplitude)
0600:30	5.775	–81 dBm (No signal, noise was –110 dBm in 1200 Hz bandwidth)
0610:30	6.775	–43 dBm (Wow, strongest signal of the night. No signal, noise was –100 dBm)
0620:30	9.575	–90 dBm (Some radar interference in the first few minutes which moved lower in frequency later)

Wenonah, New Jersey:

Mike Thompson (radio amateur call sign KG4JYA), Wenonah, New Jersey USA, geographic coordinates 39.7988° N, 75.1624° W, site elevation 66 ft ASL. The antenna was a long wire antenna and the receiver was part of a Yaesu FT-450 transceiver. The received signal levels are given in S-units, a convention and unit system used exclusively by radio amateur operators (table 5).

Table 5 ~ Log of received signal strength at Wenonah, New Jersey from Mike Thompson

Time (UTC)	Frequency (MHz)	Signal (see key)
04:30	2.775	S4
04:40	3.275	S3
04:50	4.075	S3
05:00	5.775	S1
05:10	6.775	S1
05:20	9.575	S1
05:30	Stopped observing	

Key to Signal Strength provided by observer: S1- Faint, barely perceptible; S2- Very weak; S3- Weak; S4- Fair; S5- Fairly good; S6- Good; S7- Moderately strong; S8- Strong; S9- Extremely strong.

Northwest Illinois:

Mike Otte (radio amateur call sign W9YS), northwest Illinois USA, geographic coordinates 42.21 N, 89.87 W, site elevation 800 ft AMSL. The antenna was a fan dipole for 40/80 m radio amateur wavelengths at 30 ft AGL and the receiver was part of a Yaesu FT-1000MP transceiver. The receiver audio output was connected to a PC soundcard and viewed and analyzed with SpectrumLab software. The receiver was set to USB mode and tuned 1000 Hz lower than the specified transmission frequency. The relative power levels and frequencies were determined by placing the mouse cursor near the peak of the signal on the SpectrumLab display (table 6). The highest, lowest and most frequent received signal levels were recorded. The S meter was of no use on the radio.

Table 6 ~ Log of relative audio levels recorded at northwest Illinois from Mike Otte

Frequency (MHz)	Lowest (dB)	Most frequent (dB)	Highest (dB)
2.775	–10	–6	–1
3.275	–28	–18	–10
4.075	–27	–13, –8	–4.8
5.775	–26	–16	–11
6.775	–54	–47	–43
9.575	–57	–45	–39
2.775	–28	–14, –11, –7	–1.2
3.275	–36	–24, –19	–16
4.075	–30	–22, –18	–14
5.775	–24	–18	–13
6.775	–36	–31, –25	–22
9.575	–53	–49	–49

Usually the fading was very slow, but during the second 4.075 MHz transmission period the signals faded over a few seconds. The first 6.775 MHz transmission period was inaudible but could be seen by adjusting the SpectrumLab display. During the second 6.775 MHz transmission period, the signal was well-defined but showed a *strong ghost* signal adjacent and below (maybe aurora). The second 5.775 MHz transmission period also showed a similar but narrower ghost display. There were a few *satellite-like curves* on 2.775 MHz at 05:35 that made a *full U*. I also saw a few *radar-like returns* on 5.775 MHz at 06:01:30.

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5. Weblinks and References

{NASA} https://www.nasa.gov/sites/default/files/styles/image_card_4x3_ratio/public/thumbnails/image/solar_orbiter_artist_impression_20190916_1.jpg

{Reeve16} Reeve, W., HAARP Antenna Array ~ Photographic Tour 2016: https://www.reeve.com/Documents/Articles%20Papers/Reeve_HAARP16.pdf

{STCE} http://www.stce.be/newsletter/pdf/2021/STCEnews20211126.pdf

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6. Acknowledgements

The author is grateful to Doug Ronald, Mike Thompson and Mike Otte for their reception reports and permission to use them in this article and to the HAARP operating personnel for providing the transmission data.

Document Information

Author: Whitham D. Reeve

Revisions: 0.0 (Original draft started, 26 Nov 2021)
0.1 (Added block diagrams and observer's comments, 28 Nov 2021)
0.2 (Added tables and other data, 03 Jan 2022)
0.3 (Added Anchorage and Cohoe spectra, 21 Jan 2022)
0.4 (Edits, 23 Jan 2022)

Word count: 2709

File size (bytes): 12286335