HAARP Research Campaign ~ October 2022

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1. Introduction

The High-frequency Active Auroral Research Program, HAARP, operated by the Geophysical Institute at the University of Alaska Fairbanks, held a very successful 10-day research campaign on 19-28 October 2022 (figure 1). The campaign involved over 40 investigators, 13 experiments, and approximately 78 hours of transmitter/array time. All experiments except one were funded by the United States *National Science Foundation* (NSF). The one exception was funded by the *Canada Council for the Arts*.

Figure 1 ~ Graphic that was part of the press release by University of Alaska Geophysical Institute announcing the research campaign. The foreground shows the Ionospheric Research Instrument antenna array and transmitter enclosures. The Operations Center is the white building in the left near background. The mountains in the far background are part of the Wrangell Mountains with Mount Drum on the right, 40 km away, and Mount Sanford on the left, 50 km away. Image courtesy of UAF-GI.

This article briefly describes the campaign from my perspective both as an observer and participant. The Ionospheric Research Instrument (IRI), which is the transmitter and antenna array used to heat and alter the ionosphere above the facility with several gigawatts of radiated power, is the key instrument, but many diagnostic instruments were used including my own receiver and antenna systems. Readers interested in more detailed descriptions are referred to {Reeve16} and {Reeve17} for HAARP instrumentation and {Reeve22} for my own instrumentation. The official HAARP website also has many details including links to the diagnostics {HAARP}.

2. Overview

The October 2022 campaign was the most scientifically diverse campaign ever conducted at HAARP. It included a first-ever attempt to probe Jupiter's ionosphere using signals transmitted from Earth (*Jupiter Bounce* experiment), investigation of possible causes of the airglow phenomenon known as STEVE (Strong Thermal Emission Velocity Enhancement, *MIV experiment*), and an experiment to test the feasibility of using HF radio transmissions to measure the interiors of near-Earth asteroids (*Moon Bounce* experiment). These and other experiments are described in the following sections.

Coordination and discussions between the investigators and IRI operator are through an online collaboration and communication tool. This also is used to post spectrograms, ionograms and other data including occasional snapshots of some of the monitors in the HAARP Operations Center (figure 2) located about 1 km from the IRI. The IRI operator prepares scripts before the campaign that define details of each experiment such as frequencies, modulation, array configuration, transmitter power and transmission times. If needed, the scripts can be changed relatively quickly to accommodate ionospheric conditions as a given experiment progresses.

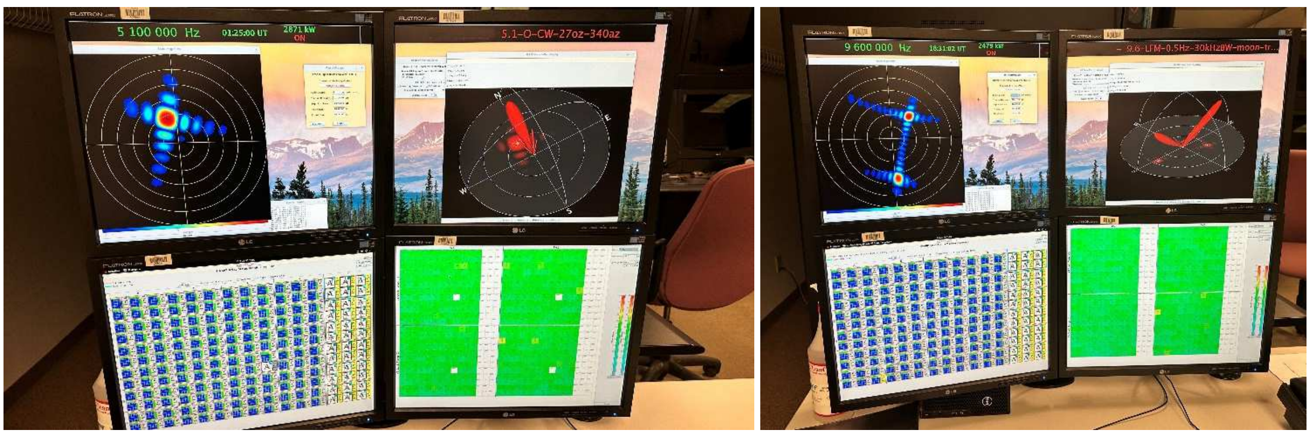

Figure 2 ~ Four of the many IRI monitors. Clockwise from top-left in each image is the IRI heat map (relative transmission power shown by color on a compass), 3-dimensional antenna pattern shown on a compass, array transmitter power amplifier cooling stack temperatures, and status of every transmitter in the array. All displays are real-time. <u>Left</u>: 5.1 MHz *PFISR* (Poker Flat Incoherent Scatter Radar) experiment at 0125 on 24 October with the array beam pointed 27° off-zenith elevation and 340° azimuth. Array gain was 26.5 dB; <u>Right</u>: 9.6 MHz Moon Bounce experiment at 1831 on 21 October with the array beam pointed 52.5° off-zenith elevation and 175.7° azimuth. Array gain was 27.0 dB. Images courtesy of UAF-GI.

There generally is no requirement that investigators be present at the HAARP facility during the campaigns unless they have on-site diagnostic instruments and need to locally control them. On the other hand, online presence is very important. Some diagnostic instruments are off-site and remotely controlled. I controlled my receiver systems at Anchorage Radio Observatory and Cohoe Radio Observatory from Anchorage, Alaska and was not present at HAARP during the campaign.

Many HAARP experiments benefit from amateur radio support or have citizen science applications, so a *Notice of Transmission* was distributed by the HAARP Program Office before the campaign to amateur radio astronomy and amateur radio groups. The transmission notice encouraged observers to submit their observations of the various experiments and provided an address for requesting a HAARP QSL card. The notice also included a brief description of the experiments and known frequencies and transmission times. Some experiments depended on knowing the ionosphere's plasma and gyro frequencies in real time. Because these naturally change, the transmission frequencies for some experiments sometimes changed with less than a minute's notice, adding to the challenges I and others had to record the received signals. Despite these challenges, I recorded over 550 gigabytes of digitized In-Phase and Quadrature-Phase (I-Q) data from three software defined radio receivers.

The campaign went very well with no major problems reported by the HAARP Program Director. On one occasion, the IRI had to be shut down for a few minutes due to an errant airplane flying toward the facility. An important step in HAARP campaign planning and execution is coordination with the Federal Aviation Administration, which issues a NOTAM before the campaign to announce temporary fight restrictions and warn pilots and dispatchers of the HAARP operation (*A NOTAM, or Notice to Air Missions, is a notice containing information essential to personnel concerned with flight operations* (for example, pilots) *but not known far enough in advance to be publicized by other means.*). The plane was detected by the on-site radar and Traffic Collision Avoidance System (TCAS), both of which were installed and are operated during research campaigns for this purpose. The pilot made no attempt to contact the facility on the air band VHF installed in the operations center.

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3. HAARP Ionosonde

Many HAARP experiments require heating of the ionosphere above the facility at natural frequencies. The IRI transmitter sometimes is called an *HF pump* because it pumps energy into the ionosphere, generally near the gyro or plasma frequencies or harmonics because those frequencies are the most efficient for heating. Thus, it is necessary to determine what those frequencies are immediately before and during an experiment. The on-site *DigiSonde* ionosonde is used for that purpose. The DigiSonde is an integral component of IRI operation, not only for experiments that produce artificial ionosphere layers or phenomena but also for experiments that involve propagation.

An ionosonde produces graphs, called ionograms, of the ionosphere's height plotted against frequency. The DigiSonde also has built-in computational capabilities and can provide plots of electron density against frequency and other information. These plots are analyzed by the array operator and investigators, and the frequency is chosen through collaboration in real-time. Sometimes, the IRI is setup to sweep through a range of frequencies in an effort to find the best frequency or frequencies for a particular experiment. Or, it may be run at a fixed frequency for several minutes to observe the effects.

The DigiSonde receiver antennas are only 0.8 km from the IRI array so interference is unavoidable when the IRI is transmitting unless specific measures are taken. In this case, the DigiSonde is switched to a *fast mode* and synchronized with the IRI to operate only during the IRI off periods. The tradeoff for the fast mode is lower signal-to-noise ratio and lower resolution ionograms, but a low-resolution ionogram can be produced in less than 10 seconds compared to slightly more than 4 minutes for a normal ionogram. The lower resolution is sufficient to spot artificial ionosphere layers, especially when a series of ionograms is viewed in succession as the artificial layer develops (figure 3).

Real-time ionograms produced by the HAARP DigiSonde at Gakona, Alaska may be viewed by visiting the HAARP Diagnostic Suite webpage {DIAGN}.

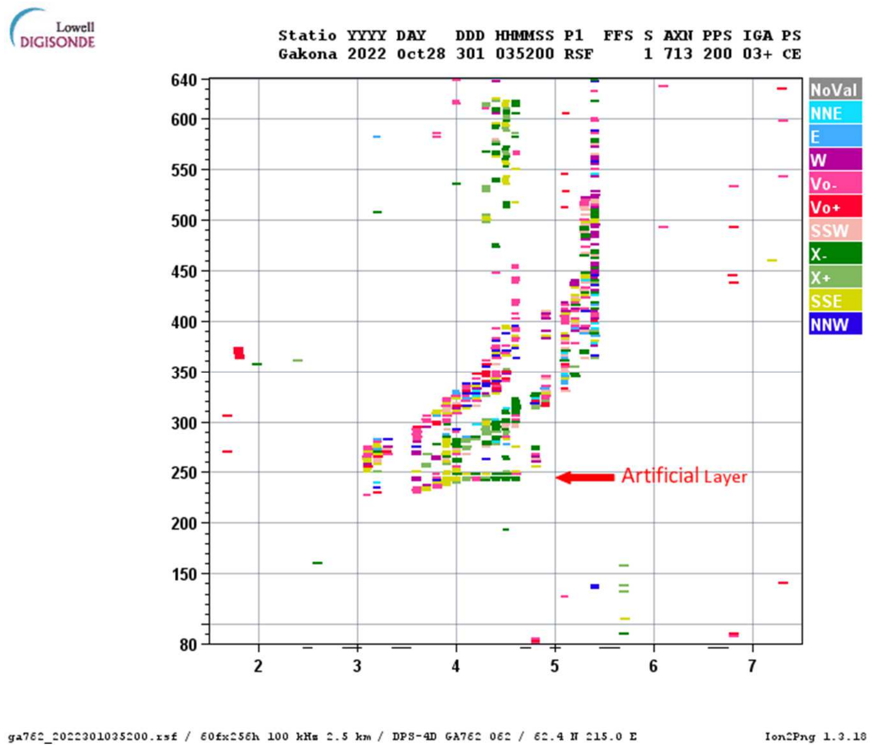

Figure 3 ~ One of a series of a low-resolution ionograms produced during a *Making the Invisible Visible* (MIV) experiment. Height above ground (km) is shown on the left vertical scale and frequency (MHz) on the lower horizontal scale. The pixel colors indicate various characteristics. The artificial ionosphere layer produced by the IRI at 240 km altitude is annotated by the red arrow. At the time shown, the IRI was transmitting a 4 minute linear slow sweep from 4.15 to 4.25 MHz. In fast mode, the DigiSonde sweeps only 60 frequencies by 256 height increments. A normal ionogram sweeps 392 frequencies by 512 height increments and integrates more pulses for each frequency to provide higher resolution and signal-to-noise ratio.

4. Experiments

The following are brief discussions of some of the experiments and the resulting signals I received at Anchorage. I simultaneously received and recorded the signals at Cohoe Radio Observatory but only show spectrograms from Anchorage. Anchorage is 286 km and Cohoe is 390 km from HAARP, and the received signals were very similar. The description of each experiment in italics is taken directly from the Notice of Transmission mentioned above.

My discussions include a screenshot of the *SpectraVue* receiver control software window. The window has three panels. The upper panel is the spectrogram with frequency shown on the horizontal scale along the top and received signal level in dBm on the left vertical scale. Received carrier waves are seen as spikes or humps and some include a marker that indicates the frequency and amplitude in a table in the upper-left corner. The displayed noise floor is the jagged line at the bottom of this panel. The middle panel is a waterfall that uses the same frequency scale as the spectrogram and shows the spectra over time from top to bottom. The waterfall spectra is time-stamped and the power is indicated by colors using a scale along the left edge of the waterfall. The bottom panel shows the center frequency, displayed frequency span and some display setup details such as the number of dB per division on the spectrogram vertical scale and displayed frequency resolution.

Making the Invisible Visible (MIV) – *Experiment using the HAARP IRI to test if hot electrons are capable of producing the continuum (white) emissions present in STEVE airglow. If successful, this experiment may provide new insights into the cause of the unique color of STEVE, a question that so far is unanswered.*

The anticipated results from the MIV experiment were optical effects similar to the STEVE airglow. The experiment also produced radio effects that I received at Anchorage. One such effect was *BUM*, or Broadband Upshifted Maximum in the stimulated electromagnetic emission spectra (figure 4). The BUM is a prominent feature produced when the HF pump frequency is close to a harmonic of the electron gyro frequency; in this case it was the 3rd harmonic at 4.27 to 4.28 MHz. I was surprised to receive the BUM because I expected it would be very weak and not detectable 286 km from HAARP at Anchorage.

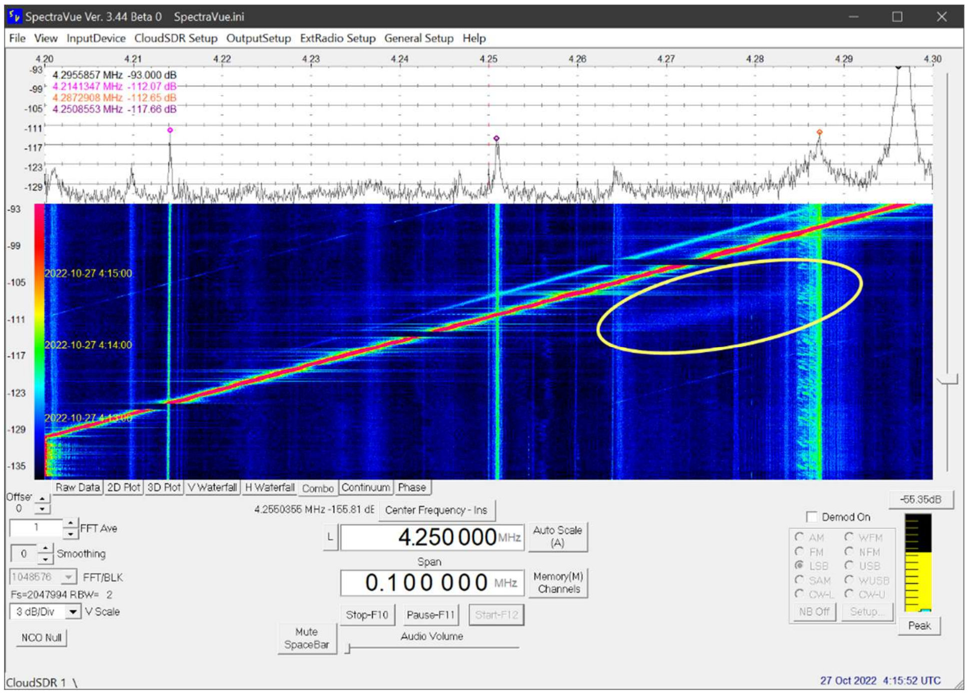

Figure 4 ~ Annotated spectra recorded at Anchorage for the MIV experiment at 0415 UTC on 27 October showing BUM - Broad Upshifted Maximum stimulated electromagnetic emissions (diffuse region circled in yellow) and considerable radio frequency interference (RFI) seen as vertical lines. The transmitted sweep is the bright, slanted line from lower-left to upper-right. The sweep required 4 minutes from 4.2 to 4.3 MHz. The BUM indicates the IRI transmissions are at an ionospheric resonant frequency and a good place for artificial plasma cloud generation. In this case, the BUM was produced when the HF pump frequency sweep was between 4.27 and 4.28. This screenshot was taken when the sweep frequency was 4.2955... MHz just before the sweep ended. Several spurious signals also are present with the three most prominent at 4.2141..., 4.2508... and 4.2872... MHz, the latter partially masking the BUM.

Moon Bounce – *A NASA Jet Propulsion Laboratory (JPL) project, in collaboration with Caltech's Owens Valley Radio Observatory (OVRO) and the University of New Mexico Long Wavelength Array (UNM-LWA), testing the potential use of HAARP/OVRO/UNM-LWA for interior sensing on near-Earth asteroids. This experiment will reflect HAARP transmissions off of the Moon, and the echo will be received by OVRO and UNM-LWA. Amateur radio enthusiasts are invited to listen to the transmissions/echos and submit reception reports to the HAARP facility at uaf-gi-haarp@alaska.edu, or by mailing a report to the address at the end of this document.*

For the Moon Bounce experiments, the HAARP IRI operated as the transmitter part of a bi-static radar with receivers dispersed at locations within view of the Moon including my observatories at Anchorage and Cohoe. The experiments were executed soon after local sunrise on 19, 20 and 21 October when the Moon was highest in the sky (about 43° elevation) and directly south of HAARP. A fixed frequency was used, 9.6 MHz. The modulation was a linear frequency sweep from 9.585 to 9.615 MHz (LFM with 30 kHz span) over a 2 second time period (0.5 Hz rate). The sweep modulated carrier was transmitted continuously during each session: 1.5 hours on 19 October and 1.0 hours on 20 and 21 October.

The Moon's distance from Earth was approximately 400 000 km and the signal's roundtrip propagation time from Earth to Moon and back was about 2.7 seconds, so any echoes fell between sweeps. The maximum radial velocity of the Moon with respect to Earth was only 67 m s^{-1} during the experiments, leading to a maximum echo Doppler frequency shift of only a couple Hz.

The HAARP outgoing transmissions were not particularly strong when received at Anchorage and Cohoe, and there was considerable unintentional foreign language shortwave broadcast station interference (figure 4). I believe the interfering stations were on the western side of the Pacific Ocean and that propagation toward Anchorage was enabled as the Sun rose above the Pacific Ocean. I did not see any obvious lunar echoes in real-time, but it is possible echoes are detectable in post-processing of the data files.

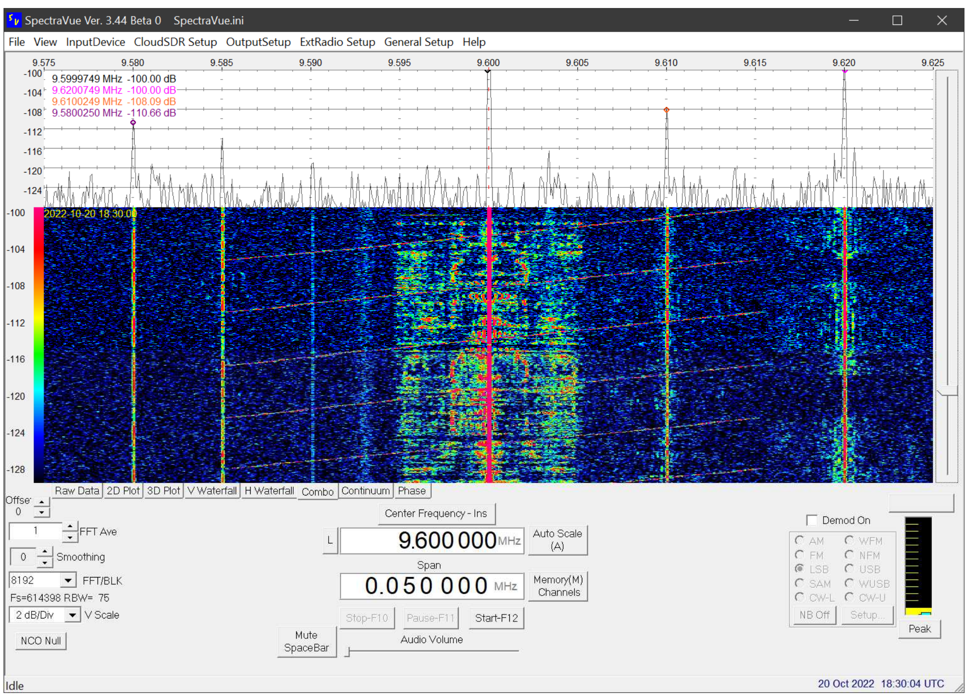

Figure 4 ~ Outgoing Moon Bounce spectra received at Anchorage at 1830 on 20 October in a 50 kHz span. The slanted lines are the sweeping IRI transmissions centered on 9.60 MHz. Shortwave broadcast stations are also received at 9.60, 9.610 and 9.620 MHz, the first two directly overlaying the experiment. Two other relatively strong non-voice transmissions are visible at 9.580 and 9.585 MHz. As the experiment progressed, various stations at 5 kHz intervals popped in and out of the monitored span, usually on the hour or half-hour.

Ghosts In The Airglow (GITAG) *– The second of a three part transmission art project, mixing audio and images at the boundary between Earth's atmosphere and outer space. Air glow and Luxembourg experiments will be paired with the AM modulation of Narrow Band Television (NBTV) video art, spoken word, and sound art created by Amanda Dawn Christie. As a citizen science experiment to learn more about propagation, shortwave listeners from around the world are invited to tune in and submit reception reports in exchange for QSL cards. Transmission frequencies will be listed on the project's new website www.ghostsintheairglow.space, and reception reports can be submitted using the online form which is also on the website. For those who do not have access to shortwave radio equipment, the project will also be streamed live on the home page of the project's website. There are frequently two frequencies transmitted simultaneously, and as such there are two videos embedded side by side (one for each frequency) that can be viewed simultaneously.*

Although the GITAG experiments were designed for artistic purposes and funded by the Canada Council for the Arts, they also had scientific characteristics useful to other investigators. The experiments required transmission of ten different frequencies, some of which changed after only 1 minute, and some transmissions used two simultaneous frequencies. For me, this made recording the experiment somewhat difficult. I had previously decided to record all experiments with the bandwidth of each receiver set to 100 kHz, so to accommodate GITAG I would have had to change recording schedules rather quickly to accommodate the frequency changes. As a result, I was able to record only a few sessions and one live screenshot from this experiment (figure 5).

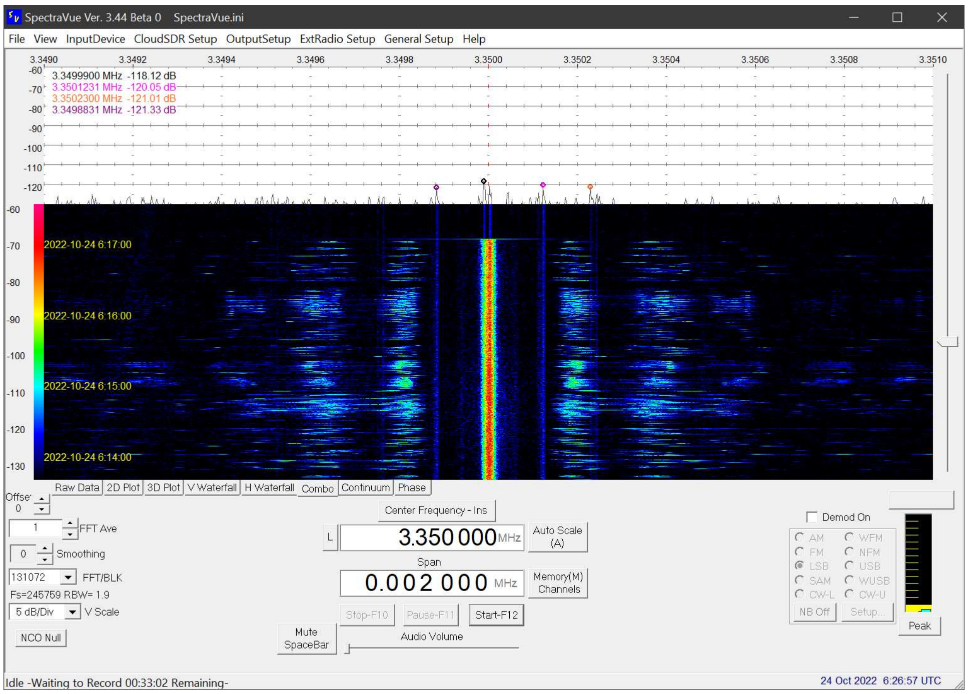

Figure 5 ~ Example GITAG spectra received at Anchorage shown in a 2 kHz span at 3.35 MHz on 24 October. This experiment consisted of simultaneous transmissions on 2.8 and 3.35 MHz, both using amplitude modulation (AM) and with transmissions directed along the magnetic zenith using O-mode (right circular polarization). These transmissions were programmed to end at 0617 as seen at the top of the waterfall. The resolution bandwidth seen in this image is 1.9 Hz.

The GITAG experiments included transmissions of voice, music and video recordings using amplitude modulation (AM). The transmissions took place both in the local mornings and late at night and some were directed east toward Canada while others were directed south of HAARP or along the magnetic zenith (MZ, the direction along the local magnetic field lines, which have an inclination of 75.5° from horizontal at HAARP). Such transmissions can cause magnetic *field-aligned irregularities* (FAI) and *field-aligned scattering* (FAS) and other phenomena in the ionosphere and are used in many HAARP experiments.

There was a possibility that some GITAG transmissions would cause the so-called *Luxembourg Effect* in which the audio that is modulating one frequency is superposed on another stronger signal frequency when the stronger signal modulates the ionosphere's electron density. This effect occurs only under the right conditions, and the superposed modulation is reported to be very weak. In the GITAG experiment, some sessions transmitted music on one frequency and voice on the other. If the Luxembourg Effect had occurred, both voice and music would be heard on one or both frequencies. I listened to both frequencies but the background noise prevented clear recognition of both voice and music so, for me, the results were inconclusive.

Interplanetary Ionosonde (Jupiter Bounce) – *Testing the use of HAARP (in conjunction with the University of New Mexico Long Wavelength Array) as an interplanetary ionosonde to measure the ionosphere of Jupiter. HF transmissions from HAARP will be directed at Jupiter, and UNM-LWA will listen for an echo off of the Jovian* *ionosphere. <u>Ham radio operators note: please remain quiet!</u> On Oct. 24, 0700-0800 UTC, we will attempt the largest active remote sensing operation in history. Due to the distances involved, it is very important that we keep the noise floor in the 2.7-10 MHz range as low as possible for the duration of the experiment.*

The Interplanetary Ionosonde, or Jupiter Bounce, experiment was another example of a bi-static radar application. Although many individual receivers were tuned to the transmissions, including my own, the only system likely to receive any echoes from the target Jupiter was the *Long Wavelength Arrays* in New Mexico.

The experiment was executed during a 1 hour period from 0700 to 0800 UTC (11 pm to 12 am local) on 23 October. During that time Jupiter was at its highest elevation, about 26° above the horizon, and south of HAARP. Nine frequencies were sequentially transmitted, starting at 2.8 MHz and ending at 9.6 MHz. The transmission cadence was 5.5 minutes ON, 0.5 minutes OFF for each frequency, and the IRI output power was 2.8 GW. The carriers were modulated with 10 kHz linear FM having a 2 second period (0.5 Hz waveform repetition rate). For example, the transmissions at 2.8 MHz swept from 2.795 to 2.805 MHz in 2 seconds (figure 6), repeated for 5.5 minutes followed by a 0.5 minute off period before the next frequency started. At the time of the transmissions, Jupiter was 4.0 astronomical units from Earth and the roundtrip propagation time was close to 66 minutes (1 AU is defined as 149.598... million km).

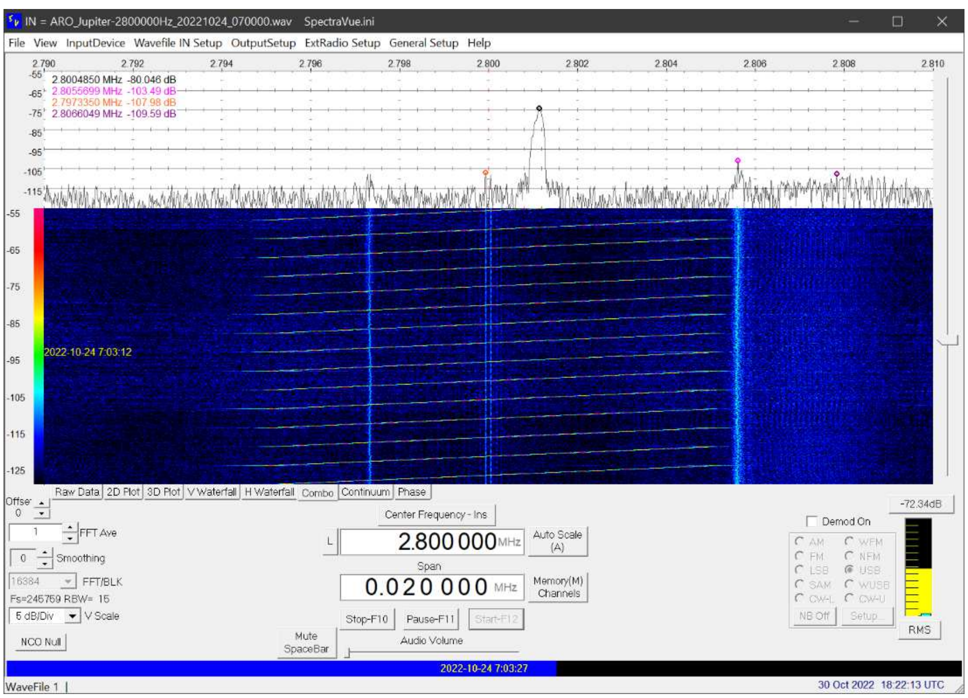

Figure 6 ~ Spectra at 0703 on 24 October for the outgoing Jupiter Bounce transmissions as received at Anchorage. The spectra is shown in a 20 kHz span and 2.80 MHz center frequency. The linear frequency sweeps are apparent in the waterfall, and the sweeping carrier was captured in the spectrogram at 2.8012 MHz just to the right of the center frequency. Return signals from these transmissions would not be received on Earth for over an hour. This image is from the playback of one of the recorded files.

A number of attempts were made in the 1960s to reflect signals from Jupiter in the UHF radio band. To my knowledge, no previous attempts have been made using HF. I did not expect to receive echoes at Anchorage or Cohoe because of the extremely low received signal levels characteristic of extreme distance propagation. In addition to the reduction of signal with distance, only a small (unknown) fraction of the signal incident on Jupiter would be reflected back to Earth. However, there was a possibility of the return signal being received by a very sensitive array such as the LWA in New Mexico. The LWA's received signals will be post-processed to see if any echoes are present, but I do not know when the results will be available.

Several other experiments were listed in the transmission notice, and I recorded signals from almost all of them. One of considerable interest to me was the *VLF Amplification* experiment. Here, *VLF* does not strictly refer to the familiar frequency band 3 to 30 kHz but to very low frequencies in general.

In the HAARP experiment, two HF frequencies are transmitted simultaneously, each using one-half of the IRI array. One frequency is modulated and is the *VLF generator*, and the other is a frequency designed to excite the ionosphere's plasma at or near its critical plasma frequency. Depending on ionospheric conditions, the transmissions can result in emissions in the approximate range 1 mHz to 30 or 40 kHz. These propagate along magnetic field lines into the radiation belts and also are received on the ground via propagation in the Earth-ionosphere waveguide. During the October experiments, the VLF generator frequency was modulated with a slow (6 second) ramp from 500 Hz to 3.5 kHz (figure 7).

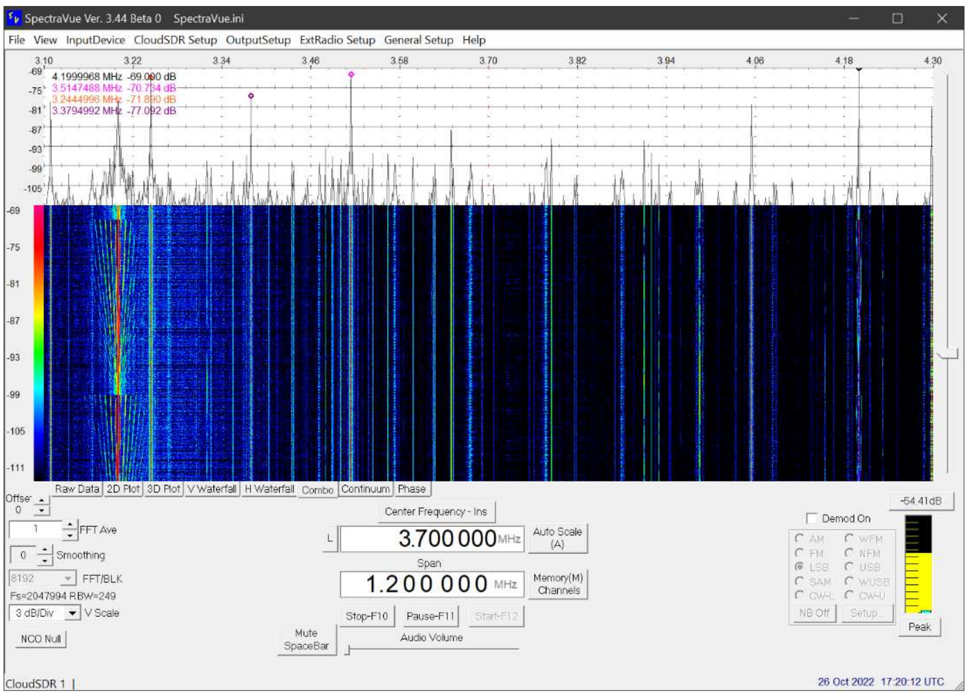

Figure 7 ~ VLF Amplification experiment received at Anchorage at 1720 on 26 October shown in a 1.2 MHz span. The displayed center frequency is 3.7 MHz, middle of the actual IRI transmit frequencies of 3.2 MHz and 4.2 MHz. The lower frequency, near the left side of the image, is modulated with a 0.5 to 3.5 kHz ramp with 6 second period and is seen as a fan-shaped waterfall. The higher frequency, near the right edge, is an unmodulated carrier wave. There are many other signals seen in the spectrum.

I am in the process of refurbishing two very large wire coils in wooden frames that I plan to use to detect the magnetic component of the emissions generated by future VLF Amplification experiments. I also am nearing the end of the construction stage of a search coil magnetometer consisting of 160 000 turns of very thin magnet wire with a design frequency range of a few mHz to a few hundred Hz, which I believe will be suitable for detecting the emissions from future VLF Amplification experiments.

Other HAARP experiments involved simple carrier wave transmissions at a fixed frequency or multiple modulated carriers but are not described here. The scientific results from all 13 experiments eventually will be published by the principal investigators but where and when is unknown at this time.

5. Campaign Weather

Investigators who traveled to HAARP for the October research campaign were met by winter weather including several inches of snow (figure 8), but they had a brief *warm* spell with blustery winds on 20 October (figure 9).

Figure 8 ~ View from a drone at about 13.8 m (50 ft) altitude of the Ionospheric Research Instrument – crossed-dipole antennas and transmitter enclosures – as the Sun was setting at the HAARP facility. Mount Drum, part of the Wrangell Mountains, is in the middle far background. This image was taken near the same location as the opening image in this article but at a lower altitude. Image courtesy of UAF-GI.

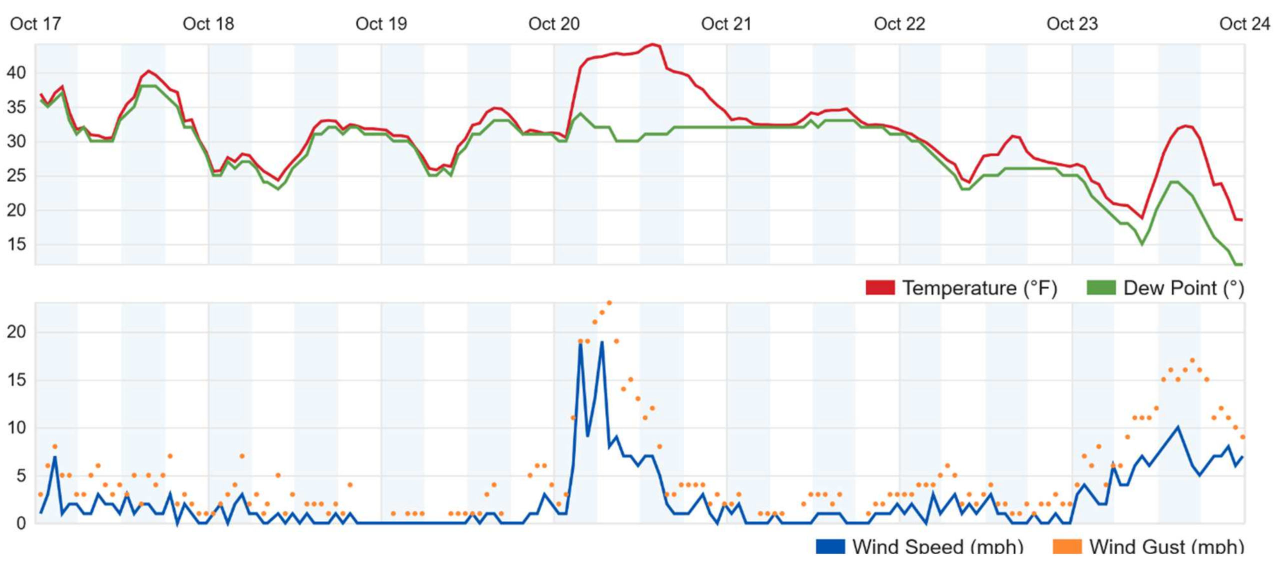

Figure 9 ~ Weather reported by the weather station at the HAARP facility. The research campaign started on 19 October with freezing temperatures and negligible winds. The temperature warmed above freezing the next day but then steadily fell, reaching –9° F on 25 October and remaining in the low twenties through the end of the campaign on 28 October. The weather station is located at the Modular UHF Incoherent Radar (MUIR) site about 400 m from the HAARP Operations Center. Source: WeatherUnderground for station KAKGAKON7 at https://www.wunderground.com/dashboard/pws/KAKGAKON7

6. Future Campaign Observation Strategies

The received signal levels at Anchorage and Cohoe for almost all experiments were generally very strong even at frequencies far below the design range of my antennas: HF Log Periodic Antenna at Anchorage and a single crossed-dipole LWA Antenna at Cohoe. During the MIV experiment on 23 October at a frequency of 4.2 MHz, the signal was so strong at Anchorage I had to set 30 dB of attenuation on the receiver input to control the displayed signal. Receiving strong signals has been the case for past campaigns as well, so no changes are envisioned for the antenna or receiver systems. However, one aspect that I intend to refine is the receiver recording bandwidths, especially for experiments that involve multiple frequencies. Since I use software defined radio receivers with wide bandwidths (RFSpace *CloudSD*R with up to 61 MHz bandwidth), this is easy to accommodate by making simple software setup changes.

My general strategy for past campaigns was to record wide bandwidths that encompassed the entire HAARP IRI frequency range 2.8 to 10 MHz. The full range, including a buffer on each end, is accommodated by a receiver bandwidth setting of 10 MHz and a center frequency of 6.4 MHz. These settings yielded aggregate file sizes of I-Q data for a given experiment that were quite large. During the October 2022 campaign, I started with this setup but then chose to limit the receiver bandwidth to 100 kHz and set the center frequency to that of the experiment. Two disadvantages soon arose: 1) Some experiments involved two frequencies but only one could be recorded at Anchorage; 2) Frequency changes, all unpredictable because of the ionosphere and some only a few minutes apart, were very difficult to follow. It is for these reasons that I intend to revert to an updated version of the previous strategy for future campaigns.

The revised strategy will use the 10 MHz bandwidth setting for all experiments except those with a single, predetermined, fixed frequency, in which case the bandwidth setting will be 100 kHz (for reference, the IRI's maximum emission bandwidth is 46 kHz). Since I often take screenshots of the dynamic spectra and waterfall, I still can narrow the displayed span and then set the displayed frequency resolution by adjusting the FFT frame size to focus on a particular signal.

There are some limitations to the foregoing setup. First, the 10 MHz bandwidth setting is limited to an FFT frame size of no more than 131 072 bits in the CloudSDR receivers. Since the receiver sampling rate for this bandwidth is 12 287 969 Hz, the highest displayed frequency resolution is 94 Hz. For comparison, the 1 MHz bandwidth setting has a 1 228 796 Hz sampling rate and the FFT frame size may be set from 2048 to 2 097 152; the highest resolution is 0.6 Hz.

The second limitation is the FFT frame size cannot be changed *on-the-fly* while recording because the receiver software requires that the recording be stopped to make the change and then restarted. This disrupts the recording schedule so it is necessary to have the displayed spectrum resolution setup beforehand. A third limitation is the SpectraVue waterfall rate is inversely related to the FFT frame size, so for higher displayed resolutions, the waterfall rate is slower. If a highly dynamic spectra is to be captured in a screenshot (for example, linear FM with 2 Hz rate), a faster waterfall rate is desirable and a lower resolution must be used.

A fourth possible limitation arises because of the wide receiver bandwidth. The radio traffic in the lower end of the HF band normally is very busy because of the relatively good propagation from distant transmitters. The lower end of the band also is very noisy with atmospheric noise and local interference sources. The cumulative effect is the possible overload of the receiver front end. The CloudSDR receivers and SpectraVue software are equipped with overload indicators, but I have never seen them lit even when the receiver is set for maximum bandwidth. Nevertheless, noise conditions and possible overload needs to be considered with each campaign.

Another modification to the recording strategy that I probably will use when two frequencies are transmitted is to setup two receivers, one for each frequency and a relatively narrow bandwidth setting. However, depending on the experiment, one or both frequencies likely will depend on the ionosphere's real-time characteristics, which can be very dynamic and thus limit the usefulness of this strategy. When a range of frequencies is to be transmitted, an alternative is to add more receivers and split the frequency band so that each receiver records part of the band. All of my installations use a receiver multicoupler or high quality RF power splitters, so adding receivers is simple.

The conclusions are: 1) The receiver setups will depend on the research campaign and the individual experiments; 2) The receiver setups can be planned only generally; and 3) A high level of flexibility is needed to accommodate the inevitable changes during research campaigns and also the radio band conditions.

As noted above, higher receiver bandwidth settings result in larger file sizes and, in turn, the need for more data storage space. This is easily handled during short campaigns by the existing 500 GB supplementary solid-state storage drive (SSD) already installed in the observatory PCs. At each observatory, the existing SSD shares space with system backups so, for long campaigns such as the one in October 2022, a larger drive would prevent data loss if a lot of the drive space is already used by backups. To improve the situation, I plan to upgrade to 1 TB supplementary SSDs; these use PCIe M.2 NVME technology and are inexpensive and easy to change.

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7. References

{DIAGN} HAARP Diagnostics: https://haarp.gi.alaska.edu/diagnostic-suite
{HAARP} HAARP website homepage: https://haarp.gi.alaska.edu/
{Reeve16} HAARP Antenna Array – Photographic Tour 2016: https://reeve.com/Documents/Articles%20Papers/Reeve_HAARP16.pdf
{Reeve17} HAARP Diagnostic Instruments – Photographic Tour 2017: https://reeve.com/Documents/Articles%20Papers/Reeve_HAARP17.pdf
{Reeve22} Solar Radio & Geomagnetic Activity Observed in Alaska During August 2022: https://reeve.com/Documents/Articles%20Papers/Reeve_Aug2022%20Radio-MagneticActiv_Alaska.pdf

Document Information

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Revisions:
- 0.0 (Original draft started, 29 Oct 2022)
- 0.1 (Added spectrograms & reformatted images, 30 Oct 2022)
- 0.2 (Minor edits to text, 01 Nov 2022)
- 0.3 (Added future campaigns section, 03 Nov 2022)
- 0.4 (Additions to future campaigns section, 05 Nov 2022)
- 0.5 (Added GITAG image, 18 Nov 2022)
- 0.6 (Additional edits, 30 Nov 2022)
- 0.7 (Completed draft and distribution, 04 Dec 2022)

Word count: 5104

File size (bytes): 4210564