HAARP Diagnostic Instruments ~ Photographic Tour 2017

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1. Introduction

Web links enclosed in braces { } are listed in section 4.

I previously reported on the *High Frequency Active Auroral Research Program* (HAARP) open house held in August 2016 {Reeve16}. In that article, I briefly reviewed the history and purpose of the HAARP facility and focused on the main transmitters and antenna array that form the Ionospheric Research Instrument, or IRI (figure 1). The IRI's job is to heat and stimulate the ionosphere above the site. Measurements of the effects are made by other *diagnostic instruments*, most located at the facility or within 10 km. A good background source for diagnostic instruments information, although somewhat out of date, is {HAARP02}.

Figure 1 ~ The HAARP antenna array and transmitter enclosures that are part of the Ionospheric Research Instrument. Image originally published in {Reeve16}. © 2016 W. Reeve

A highly detailed website was previously available that displayed real-time data from many of the HAARP instruments (cached static webpages are at {HAARPC}). The present facility does not have all the instruments that were originally installed when the US Air Force operated the facility. The original website was decommissioned and some instruments were removed when the facility was transferred to University of Alaska Fairbanks Geophysical Institute (UAF GI). The present website is {HAARP} but it has no data displays

The HAARP facility land area is slightly more than 200 000 m^2 and is dotted with science pads and stations accessed by gravel roads through the black spruce forest and marshy tundra that cover the site. My visit in

August 2017 (figure 2) forms the basis for the following descriptions of the many diagnostic instruments. I did not have access to any indoor electronic equipment, only the outdoor facilities – mostly antennas – so that will be my focus here. This report does not cover all instrumentation but it catches most of those within view of the access roads. The original HAARP diagnostic instruments included off-site facilities for ELF and VLF receivers located 10 km away but I was unable to determine if they still exist.

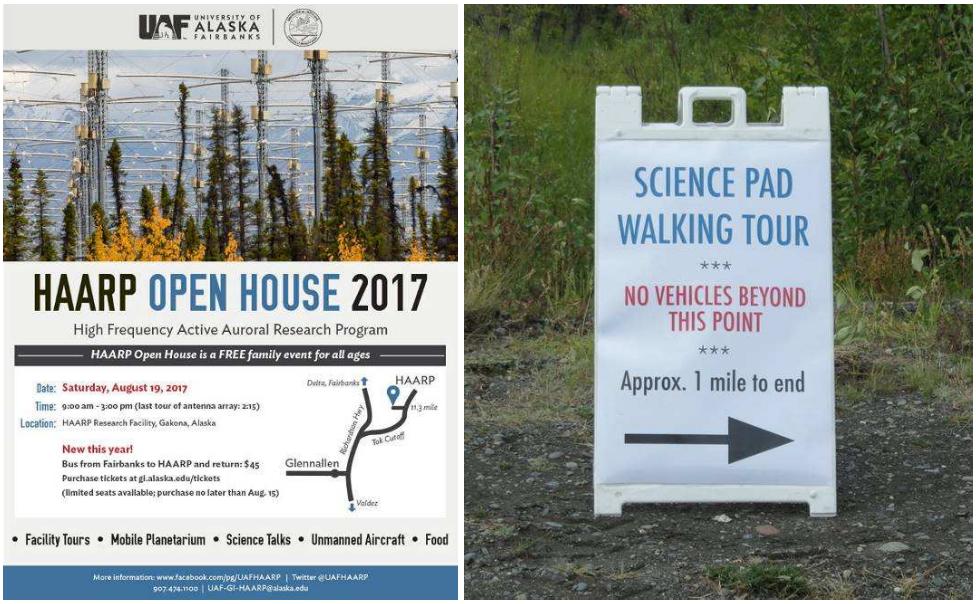

Figure 2 ~ Left: Brochure for the 19 August 2017 open house. Right: Tourists could drive to the IRI antenna array on the HAARP site but a little walking was required beyond that. Alternately, tour buses supplied by the UAF GI carried people to the science pads along the access roads. Weather during the open house was normal for early fall in interior Alaska with temperatures around 15 °C. Brochure image source: UAF GI

Figure 3 ~ Annotated satellite view of the HAARP facility about 13 km northeast of Gakona, Alaska (location shown on inset). The image dimensions are approximately 5 x 3 km. The antenna array for the IRI at Station 1 is the rectangular area near lower-center of image. All instruments are installed along gravel roads accessed from the Glenn Highway (Alaska Highway 1), which runs from lower-center to upper-right. Underlying image source: Google Earth

2. Science Pads, Stations and Diagnostic Instruments

The diagnostic instruments are grouped on *Science Pads* and *Stations*, most along gravel roads west and north of the main IRI antenna array located on Station 1 (figure 3). The science pads typically are gravel pads built on the tundra and have walk-in enclosures for electronic equipment. The science pads include radar, HF, VHF and UHF receivers, ionosonde transmitter, antennas, optical telescopes, all-sky cameras, Global Navigation Satellite System (GNSS) receivers for timing and frequency control, magnetometers, and a seismic station. Some instruments are not serviceable and are awaiting repair.

Station 2, Aircraft Alert Radar (AAR): The AAR (figure 4) is used anytime the IRI is operating. According to information provided at the open house, if an aircraft is detected within 2.5 nautical miles (4.6 km), the IRI transmitters are automatically shut down. Also at this station are a ground-based Traffic Collision Avoidance System (TCAS) and an Automatic Dependent Surveillance – Broadcast (ADS-B) system. These two transponder-based systems operate in the L-band at 1030 and 1090 MHz and originally were designed for use in aircraft. No information is available that describes how they have been adapted for use on the ground at HAARP but it is likely they operate simply in a passive mode.

Figure 4 ~ Aircraft Alert Radar, TCAS and ADS-B systems are grouped at Station 2. The radar antenna is at the top of the taller tower near image center, and the L-band antenna for the TCAS and ADS-B systems are on the stub tower adjacent to the equipment enclosure. The stub tower is heavy duty and more like a small tower one would find on a mountain-top site. The green cabinet in the right-foreground is for medium voltage ac power distribution, which continues beyond this station to Station 3 about 300 m to the west.

Station 3, TCI-540 Antenna: The TCI-540 is an omni-directional horizontally polarized HF antenna with a nominal frequency range of 4 to 30 MHz. It is manufactured by TCI International {TCI}. The antenna elements are supported by four guyed lattice towers, each about 30 m high (figure 5). The highest frequency elements are at the bottom and longer-length lower frequency elements are stacked upwards. The antenna has good low-angle response and primarily receives skywaves, but I was not able to determine its actual purpose. I did not hike to the antenna location so the photograph shows the associated towers in the background a couple hundred meters away.

Figure 5-a ~ The four 30 m high guyed towers associated with the TCI-540 antenna are visible in the background and an instrumentation hut with a GNSS antenna is in the foreground. The red objects in the foreground are vehicle barricades.

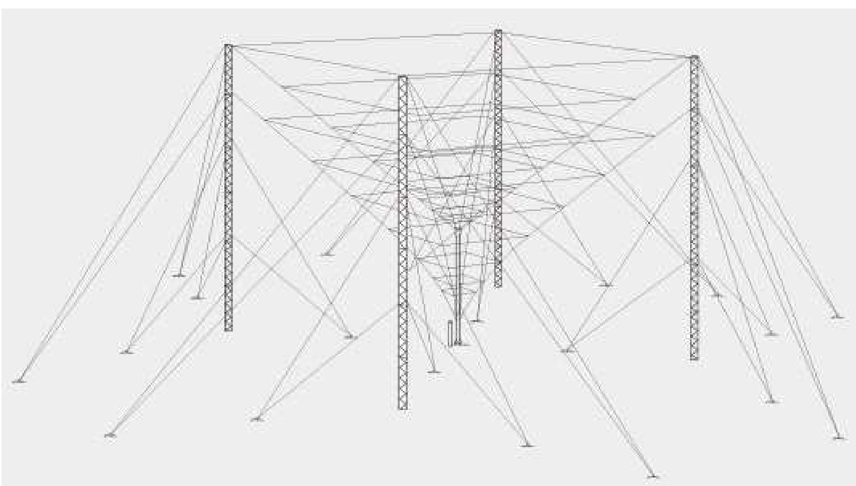

Figure 5-b ~ A line drawing of theTCI-540 shows more clearly how the antenna elements are stacked with the shorter, higher frequency elements at the bottom. A set of guy wires support each triangular tower at 10 m intervals and additional guys are installed to offset the tension of the strands that support the antenna elements.

Science Pad No. 1, Station 6: The equipment enclosure (figure 6) serves the Ionosonde and VHF and UHF satellite scintillation receivers. The ionosonde is an HF radar used to measure the height versus frequency and other parameters of the plasma layers in Earth's ionosphere directly above the site. Its nominal frequency range is 2 to 20 MHz. At HAARP, its main purpose is to determine ionospheric conditions before and during IRI experiments and to help the researchers decide what frequencies are of most interest. To indicate its computerized operation and signal processing capabilities, this ionosonde is called a {Digisonde}. The Digisonde transmitter antenna (figure 7) is located 150 m south of the equipment enclosure and the associated receiver antennas (figure 8) are located 150 m north.

Figure 6 ~ Equipment enclosure for the ionosonde electronics and scintillation receivers. Foliage quickly reclaims any remote site in Alaska, enhanced by long daylight hours in spite of the relatively short summer growing season.

Figure 7 ~ Digisonde transmitter antenna. Information available about the diagnostic instruments says the three towers support a crossed-delta antenna configuration; however, it appears the configuration has been changed to (or always was) a fan or folded dipole. I was not able to determine the actual configuration from the access road. Two towers are clearly visible at image center and a third is barely visible just to the lower-right of the center tower.

Figure 8 ~ Digisonde receiver antenna. The foreground of this image shows one of four receiver antennas built on a wooden platform. Three such antennas are arranged in an equilateral triangle (60 m spacing) and one at center (seen directly behind in the background). Each antenna consists of a 1.5 m crossed-loop assembly (turnstile), which is sensitive to the horizontal magnetic component of the transmitted radio wave reflected from the ionosphere.

Figure 9 ~ Scintillation receiver antennas. The VHF and UHF turnstile antennas are mounted collinearly. Each antenna is installed approximately 1/2-wavelength above an elevated ground screen in the center of this image. The ground screen appears to be about 1.5 m above the tundra. The ground screen platform is unevenly sinking into the gravel pad, a common problem in permafrost environments unless thermal piles are installed to prevent thawing. A chain-link fence with barbed-wire is in the background.

Collocated with the equipment enclosure are two crossed-dipole antennas for the VHF and UHF satellite scintillation receivers (figure 9). The scintillation receivers measure amplitude and phase irregularities introduced by Earth's ionosphere into satellite signals. These measurements are used to determine the total electron content (TEC) between the satellite and receiver, which is a parameter used in space weather forecasting and of particular interest in the operation of the Global Positioning System (GPS) and other Global Navigation Satellite Systems (GNSS).

Station 4, Seismic Station: The seismic station (figure 10) is on the opposite side of the access road from the ionosonde transmitter antenna. The hand-out provided at the open house mentions that it is part of the Alaska seismic network (AkSN}; however, when I contacted the Alaska Earthquake Center, I was told the station actually is part of a large-scale National Science Foundation (NSF) funded project called EarthScope. It is a USArray transportable array {USArray} and considered a partner station in the Alaska seismic network. In any case, the HAARP seismic station apparently is not directly related to HAARP research.

Figure 10 ~ Seismic station at Station 4 is set on marshy tundra flanked by scrawny black spruce trees. This station is a "partner station" in the Alaska Seismic Network.

Figure 11 ~ The RF Radiation Hazard sign is located near the ionosonde receiver antennas on the access road to Science Pad 3, but it is not obvious what transmitters or antennas present the hazard around this location, which is about 700 m from the very powerful IRI antennas that are passed along the way.

<u>Science Pad 2, Station 7, HF Receiving Site</u>: An enclosure at Station 7 houses a *Spectrum Monitoring Station* and equipment associated with a small weather instrument tower and a Spira-Cone antenna (figure 12). The Spira-Cone antenna at this station had suffered wind damage and obviously was not serviceable at the time of my visit. Nevertheless, it is an interesting antenna. The Spira-Cone is a form of log periodic array with a frequency range from 2 to 30 MHz. According to a report from 2002 {HAARP02}, the antenna is used for HF spectrum monitoring and also for HF communications purposes, presumably with outlying stations.

The Spira-Cone is mechanically very complicated, being composed of two conductors wound in spiral patterns starting at a lower elevation. The conductor vertical spacing and spiral diameter increases as the height increases. The spiral structure increases the antenna bandwidth and its orientation provides a vertical directional characteristic. According to information I found online {CPII}, the antenna has horizontal elliptical polarization. This means the antenna produces and is sensitive to an electric field vector that traces out a horizontally oriented ellipse rather than simple horizontal linear or horizontally oriented circular polarization.

Figure 12-a ~ Science Pad 2, Station 7 includes an electronic equipment enclosure for the spectrum monitoring station (left) and a Spira-Cone Antenna (right). The antenna has been damaged and is awaiting repair – see related images below.

Figure 12-b ~ Spira-Cone Antenna for HF spectrum monitoring. The wind damage to the antenna at the HAARP facility makes it difficult to determine its actual configuration, which is made clearer in the images below.

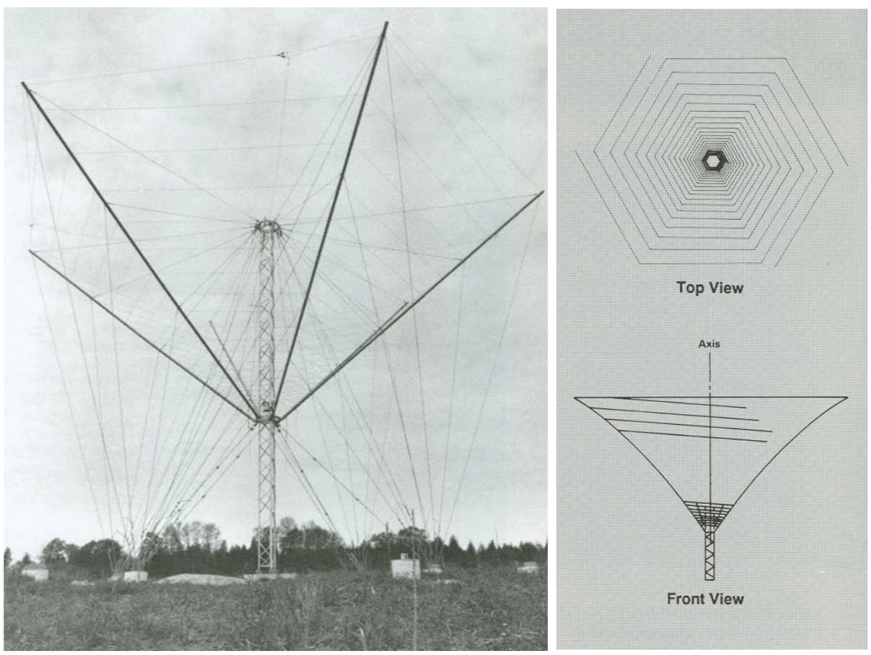

Figure 12-c ~ Spira-Cone Antenna. Left: Photograph of a working installation. Right: Line drawing of antenna. Both images were taken from a Spira-Cone brochure.

Science Pad 3, Station 8: Science Pad 3 is the largest gravel science pad at about 5600 m^2. It contains numerous instruments including optical telescopes, all-sky cameras, fluxgate magnetometer and an interesting 30 MHz Imaging Riometer. Four walk-in enclosures house the associated electronic equipment (figure 13). Evidence of prior ownership by the United States Air Force is scattered around the facility (figure 14).

Figure 13 ~ Above: Walk-in enclosures for electronic equipment at Science Pad 3, Station 8. This view is to the south. The 4 m diameter moveable dome for the optical telescope is easily seen on the third enclosure from left. The telescope is used to obtain magnified images of visible auroral during HAAARP experiments. Two 1.5 m diameter optical domes for all-sky cameras are visible on the far-right and far-left enclosures. Left: Enlarged view of the left (eastern) optical dome.

Figure 14 ~ The US Air Force previously controlled the HAARP facility but did not take any signs when it removed its equipment from the site. To my knowledge the Air Force never held a public open house during its tenure but, of course, it did host politicians who controlled US taxpayer's money that funded the facility.

Of most interest to me are the Imaging Riometer and magnetometer. *Riometer* is an abbreviation for Relative Ionospheric Opacity Meter. A Riometer is a very stable receiver used to monitor the galactic background radiation and, indirectly, the opacity of Earth's ionosphere. The average radio background is nearly constant, so any variation in the received radiation is interpreted to mean that it has been absorbed or disturbed in the ionosphere and atmosphere. Regular sidereal and diurnal variations in the received background radiation usually are nulled in the data analysis. The Imaging Riometer is able to be steered to a relatively limited specific region of the sky above the site. HAARP experiments are designed to alter the ionosphere directly above the site and the resulting changes may be detected by this Riometer.

When HAARP originally was built, a so-called *Classic* Riometer was installed. This consisted of a 2x2 array of 5-element crossed-Yagi antennas operating near 30 MHz and pointed at zenith, or straight up. At some point these antennas were damaged (figure 15) and replaced by an array of crossed-dipole antennas that presently look like a 2 m high turnstile antenna forest (figure 16). The current Imaging Riometer uses an 8x8 array (64 total) of crossed-dipoles that operate near 30 MHz; diagnostic instrument documentation {HAARP02} indicates smaller array configurations have been used in the past.

As radio waves propagate through the ionosphere and if propagation is almost aligned with Earth's magnetic field lines, the waves split into ordinary (O) and extra-ordinary (X) wave mode components. The polarization of the combined radio wave changes progressively as it travels through the ionosphere, a phenomenon called Faraday Rotation. In the northern hemisphere, the polarization rotates counter-clockwise as viewed by an observer on the ground looking up. The crossed-dipole antennas are setup for fixed circular polarization and presumably are sensitive to this direction.

All HAARP instrumentation requires accurate time and frequency control, which is provided by a GNSS receiver at each science pad. At Science Pad 1, the GNSS antenna is supported on an 8 m long carbon dioxide filled thermal pile that has been placed in the tundra near the imaging array (figure 17). The piling keeps the soil frozen and prevents movement as the soil active layer freezes and thaws with the seasons, an especially important requirement for the nearby seismic station.

HAARP originally was equipped with two magnetometers, a fluxgate magnetometer (figure 18) and an induction magnetometer. The fluxgate magnetometer uses a highly permeable ring core (see {FlxGt} for a description of operation). The induction magnetometer apparently was removed by the US Air Force in 2014.

I noted a twin dipole installation near the northwest corner of Science Pad 3, Station 8 (figure 19). This appears to be a temporary installation hand-built from scrap material. The dipole lengths are roughly 5.5 m indicating a frequency of about 27 MHz. They are separated by about the same distance (5.5 m) and are about 1.5 m above the ground. Although I was not able to determine the purpose of these dipoles, it is possible they are the partial remains of one of the earlier 1x16 Riometer antenna array. If so, my length estimates are wrong because that Riometer operated at 38.6 MHz and 1/2-wavelength would be closer to 3.9 m.

Figure 15 ~ The remains of the Yagi antenna array originally used in the Classic Riometer are now piled in the boneyard. These were made with yellow anodized aluminum elements and (I believe) originally manufactured at the UAF GI in Fairbanks. The elements are approximately 1/2-wavelength long at 30 MHz, or about 5 m. When I took this picture, I believe I was standing near the location of the previously removed induction magnetometer. In the right-background is a coil of surplus fiber optic cable inner-duct and in the left-foreground is what appears to be an unused protective cover, purpose unknown.

Figure 16-a ~ Forest of 30 MHz crossed-dipole turnstile antennas for the Imaging Riometer through the horizontal center of this image with a black spruce forest in the background. The white object left of center is the beamformer for pointing the array.

Figure 16-b ~ One of 64 crossed-dipole antennas in the 8x8 Imaging Riometer. The 1/4-wavelength coaxial phasing cable is seen looping between the two antennas center sections. The beamformer is right of center and the equipment enclosures can be seen in the far-right background.

Figure 16-c ~ The guyed 2 m mast (right of center) that supports each crossed-dipole is anchored by what appears to be a buried (or driven) stake. The coaxial cables are the same length for all antennas and the excess lengths of those located close to the beamformer are coiled and stored on the ground as shown here.

Figure 16-d ~ Beamformer. The fixed length cables from each antenna assembly terminate in the beamformer whose purpose is to steer the array's directional pattern by adjusting the amplitude and phase of each antenna under control of the array electronics. Cables from the antennas can be seen entering the beamformer on the right side.

Figure 16-e ~ Each 30 MHz turnstile antenna assembly consists of two identical horizontal dipoles mounted at right angles to each other. The short rods above and below the main antenna elements are for impedance matching in conjunction with a balun for connection to the unbalanced coaxial cable. The two antennas are connected by a fixed-length 1/4-wavelength phasing cable. Remnants of a recent rain or morning dew can be seen dripping from the horizontal elements.

Figure 16-f ~ Another view of the array showing the many guy wires that support the turnstile antenna masts. Two insulators (gray egg-shaped objects) are used on each mast guy wire. The insulators are necessary because the length of the guys are on the order of 1/2-wavelength and if not broken up could detune and alter the antenna patterns.

Figure 17 ~ One of several GNSS receiver antennas at the HAARP facility. This one is installed on a thermal pile at Science Pad 3. The thermal pile keeps the ground frozen year-around to prevent movement throughout the seasons. The 8x8 Imaging Riometer and the barbed-wire chain-link are in the background.

Figure 18 ~ Fluxgate magnetometer is housed in a weather-proof circular canister and set on a gravel pad near but not actually on Science Pad 3. The pad is surrounded by marshy tundra and black spruce trees. This unit uses a ring core and from the access road looks like a repurposed refuse container.

Figure 19-a ~ Two dipole installations at Science Pad 3. The dipole lengths are about 5.5 m corresponding to a frequency near 27 MHz. The dipoles are setup about 1.5 m above ground level and oriented true north-south. It is somewhat difficult to discern in this image but a set of three support masts are visible in the foreground and another set is behind. These may be remnants of an earlier 1x16 Riometer array that operated at 38.6 MHz.

Figure 19-b ~ Dipole installation. Local materials are used to anchor the masts in what appears to be a temporary installation. The galvanized steel ground screen with 150 mm mesh dimension is visible.

3. Future

I missed a few instruments during the 2017 open house, such as the Modular UHF Ionospheric Radar (MUIR) near the Operations Building, and plan to return to HAARP in 2018 to cover them – assuming UAF GI will host an open house then. I also hope to hike to the TCI-540 antenna for better pictures, investigate the ionosonde antennas and to visit the ELF and VLF receiver stations about 10 km from the HAARP facility if they still exist.

4. References and Web Links

{AkSN}	https://earthquake.alaska.edu/network
{CPII}	www.cpii.com/docs/datasheets/356/3000-2012.pdf
{Digisonde}	http://digisonde.com/index.html
{FlxGt}	http://www.sensorland.com/HowPage071.html
{HAARP}	http://www.gi.alaska.edu/haarp/
{HAARPC}	http://209.161.165.151:3180/haarp/index.html
{HAARP02}	http://handle.dtic.mil/100.2/ADA426081
{Reeve16}	http://www.reeve.com/Documents/Articles%20Papers/Reeve_HAARP16.pdf
{TCI}	https://www.tcibr.com/product/tci-model-540-omni-gain-antenna/
{USArray}	http://usarray.org/alaska

5. Acknowledgements

I am grateful to the UAF GI HAARP staff, which hosted the 2017 open house and helped me identify some of the objects in my photographs.

Document information

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