New Radio Observatory Established at HAARP in Gakona, Alaska

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1. Introduction

The **High Frequency Active Auroral Research Program** (HAARP) facility near Gakona, Alaska was transferred by its original owner, the US Air Force, to University of Alaska Fairbanks – Geophysical Institute in 2015. UAF-GI hosted its first public open house at HAARP in 2016 and also held open houses in 2017 and 2018. I attended all three events and published articles about the first two at {Reeve16-1} and (Reeve17}. I also observed radio transmissions from the HAARP research campaigns in spring, summer and winter 2018 and published related articles at {Reeve18-1}, {Reeve18-2} and {Reeve18-3}. The HAARP site engineer came across these articles on the Internet in early 2019 and, as a result, invited me to take a personal tour of everything on the site including several instrumentation installations that I had missed or could not access during the public open houses.

One of those installations was an unused TCI-540 HF antenna described in the next section. I previously saw the antenna towers in the distance but I did not have rubber boots necessary for walking through the wet tundra to the antenna site. In April 2019, I took my boots to the HAARP facility and I hiked with the site engineer to the antenna. I was very impressed and remarked to him “I sure would like to connect to that antenna!”. He replied “You can, just submit a proposal to the HAARP program manager!”, which I did after returning to Anchorage. I proposed to establish a radio observatory at HAARP using the TCI-540 for amateur space weather and radio propagation studies, and it was immediately accepted. An overhead view shows the site (figure 1).

Figure 1 ~ Aerial drone view in June 2019 from about 400 ft altitude (AGL) looking west. The TCI-540 antenna site is in the left-background and the gravel pad for the equipment enclosure is in the foreground. The clearing for the antenna is 160 000 ft^2 (~15 000 m^2) and for the pad is 46 000 ft^2 (4300 m^2). At one time, the equipment pad included at least two buildings to support the DoD project, but these were demolished before UAF-GI took possession of the facility. The ground-laid coaxial cable transmission line follows a path from the equipment shelter to the southwest the corner of the pad and through the woods directly to the antenna center support described later. Image courtesy of HAARP Program Manager, UAF-GI.

This article briefly describes the radio observatory I established during summer 2019. The initial projects are described in the following sections and include the TCI-540 HF antenna (section 2), associated preamplifier and transmission line (section 3), receiver common equipment (section 4), a Callisto instrument with up-converter (section 5), and a Cloud-IQ software defined radio (SDR) receiver (section 6). Also included are descriptions of the Radio JOVE installation including the receiver, dedicated dual dipole antenna and software (section 7) and future applications (section 8). The system block diagram shows the major components (figure 2).

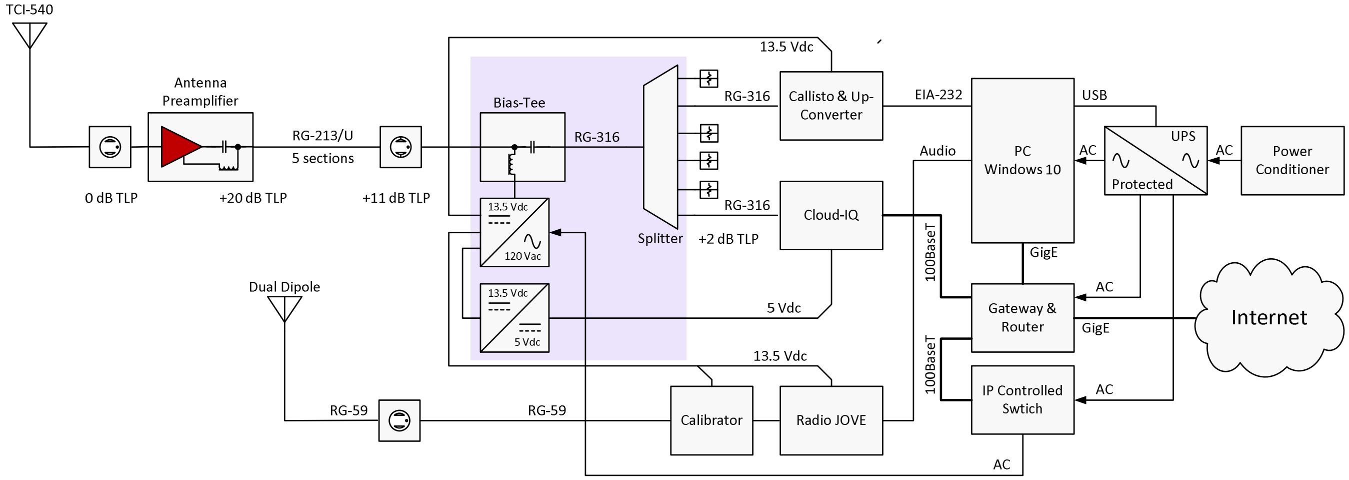

Figure 2 ~ System block diagram showing major components including antennas, transmission path components, common equipment and receivers. All components except the antennas and Radio JOVE receiver were setup and tested in my Anchorage lab before moving to the HAARP facility. The Transmission Level Points indicated here are at 30 MHz. Image © 2019 W. Reeve

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2. TCI-540 HF Antenna

The model TCI-540-N-02 omni-directional HF antenna at HAARP was manufactured by TCI International {TCI540}. It was installed around 2008-2009 by a small group from the US Department of Defense that was working on some HF radio developments. It was used only intermittently for general-purpose receive-only applications. The antenna had been obtained as used surplus from another government site [DoD].

The antenna consists of four 100 ft (30.5 m) guyed lattice towers placed in a square pattern with 130 ft (39.6 m) separation distance. The towers are in an open area 400 x 400 ft (122 x 122 m) that was cleared by an industrial brush clearing machine. The towers and guy anchors are placed on steel pilings with unknown depth (figure 3). The horizontal wire elements are placed in layers and tied together to form two inverted square cones (figure 4). According to the antenna datasheet, the antenna is within 1 dB of omni-directional in the horizontal plane, and the main lobe in the vertical plane has relatively low elevation angles that depend on frequency (figure 5). The antenna is horizontally polarized and does not use a ground-plane or counterpoise. The design frequency range for 2:1 or better VSWR is 3 to 30 MHz, but as a receive-only antenna I expect it to work over a much wider range.

The antenna element wires and tower supporting guy wires appear to be 7/16 in (11 mm) diameter galvanized steel strand. According to TCI technical support, the antenna has a built-in spark gap for lightning and static build-up protection. A balun provides the interface between the balanced antenna feedline, which is suspended from the support structure, and the 50 ohm coaxial cable transmission line. The balun is mounted about 12 ft (3.7 m) above ground level. Tubular impedance matching feedline elements extend vertically from the balun about 15 ft (4.6 m) (figure 6). The balun connects to the antenna preamplifier RF input through a gas-tube lightning protector and a jumper cable that is 16.7 ft (5.1 m) long (the preamplifier is described in the next section).

Figure 3 ~ Typical guy anchor consists of a steel piling capped with a bracket for fastening the guy strand turnbuckles. The piling is wrapped with polyethylene sheeting that provides a sliding surface to prevent frost jacking. The base of one tower is seen in the upper-left-background. It uses a similar piling except the top is capped with a 1 in thick steel plate on which the tower is placed. Image © 2019 W. Reeve

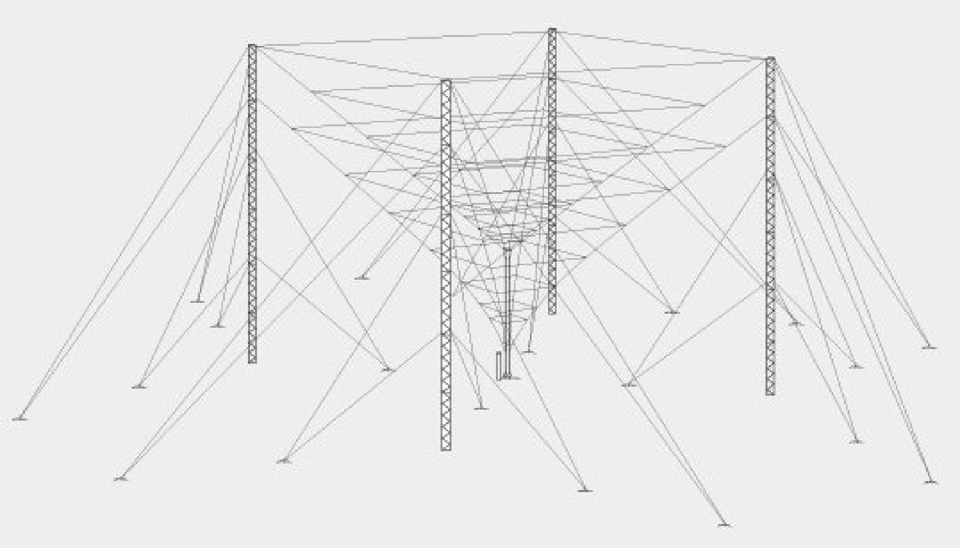

Figure 4.a ~ Line drawing of the TCI-540 antenna showing the extensive mechanical structure that supports the stacked antenna wire elements suspended from the four towers. Images source: TCI International TCI-540 datasheet

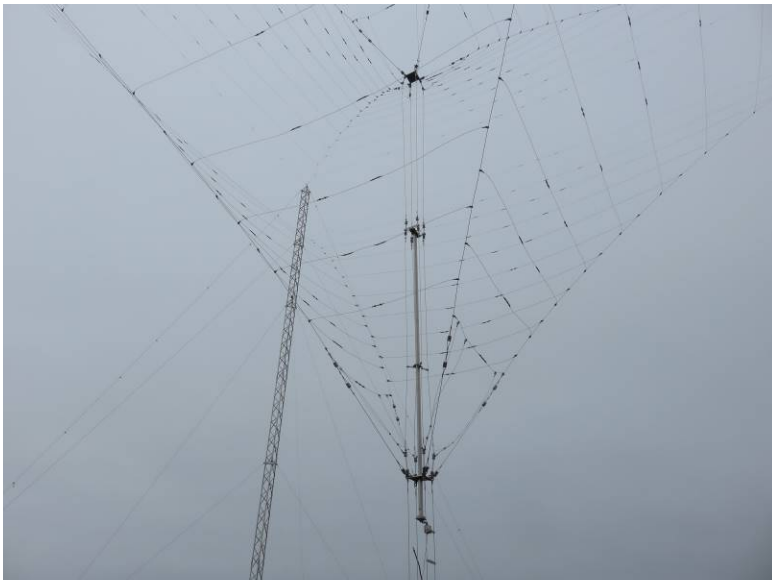

Figure 4.b (left) ~ Image from the ground of some of the stacked antenna wire elements for the lower cone and the impedance matching structure. The elements couple to the impedance matching structure in the middle. The balun is at the base of the structure; see text. One of four towers is in the left-background. Image © 2019 W. Reeve

Figure 5 (below) ~ Radiation patterns at six frequencies between 3 and 30 MHz. The antenna gain varies from approximately 6 to 10 dBi throughout the frequency range. Images source: TCI International TCI-540 datasheet

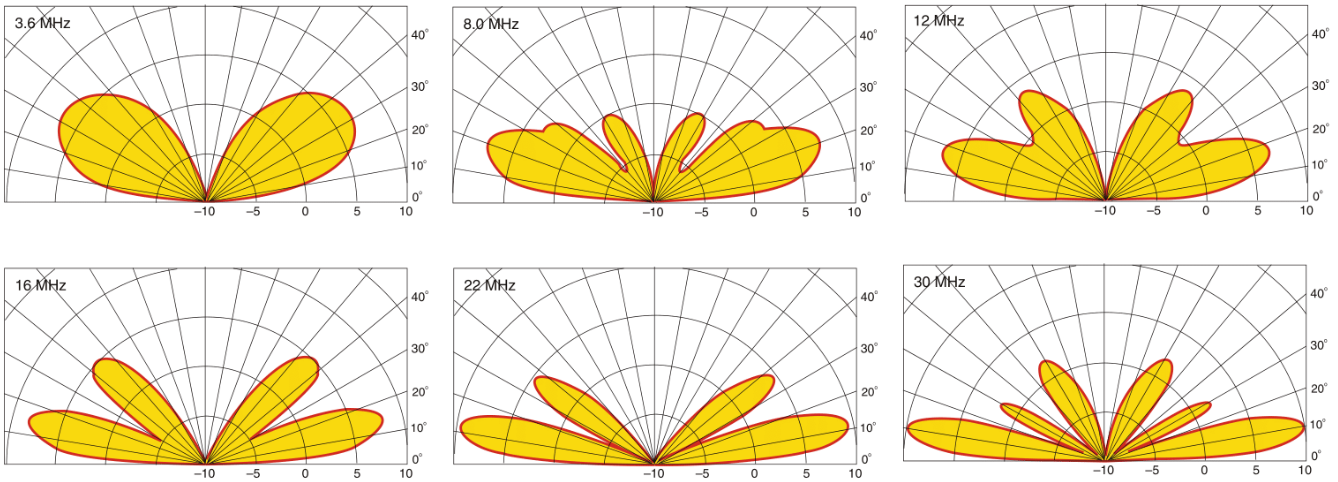

Figure 6 ~ Balun (lower box) and balanced impedance matching and coupling tubes. Flexible braid conductors are visible between the balun and matching tubes. All structural and antenna wire components appear to be made from galvanized steel strand. Image © 2019 W. Reeve

3. Preamplifier & Transmission Line

The coaxial cable transmission line from the antenna to the equipment enclosure is 772 ft (235.4 m) long and consists of five connectorized cable sections (type N-F connector on one end and N-M on the other) averaging about 154 ft (47.0 m) in length. This cable is very high-quality RG-213/U that was salvaged in September 2018 from the previously decommissioned UAF-GI imaging riometer at Poker Flat Rocket Range about 320 km north-northwest of the HAARP facility. To prevent rodent damage, the cable was pushed through several 100 ft (30.5 m) sections of 1 in (25 mm) plastic water pipe left over from another project. Before enclosing the cable connections, each one was wrapped with rubber mastic tape followed by two layers of professional grade vinyl electrical tape or cold shrink electrical tubing as the cable installation progressed. The water pipe sections were coupled with steel couplers, taped and ground-laid (figure 7). A 10 ft (3.1 m) entrance jumper cable connects the entrance protector at the equipment enclosure to the RF common equipment.

Figure 7 ~ Plastic water pipe used to protect the coaxial cable from rodent damage and tramping by moose. The pipe sections were coupled and taped as shown here. Image © 2019 W. Reeve

The computed insertion loss of the transmission line is 9 dB at 30 MHz. Additional components in the transmission path are the bias-tee and 6-port RF splitter with an added loss of approximately 9 dB, giving a total transmission path loss of 18 dB at 30 MHz. The added loss raises the system noise figure by 18 dB. Without this added loss the galactic radio background and atmospheric noise would dominate the system noise in the HF range. However, since the degradation in the noise figure due to the added loss is on the same order as the natural noise, I decided to install a low noise preamplifier at the antenna to compensate (figure 8). From an operational standpoint, the system noise figure should be at least 10 dB better than the natural background noise.

The preamplifier selected for the HAARP application is an Advanced Receiver Research model P1-30/20VD-C, which has an advertised noise figure of 2.5 dB (not verified) and 20 dB gain (verified). With 18 dB of added loss between the amplifier and receiver, the cascaded system noise figure is about 3.8 dB, about 14 dB lower than the background noise. Although the amplifier datasheet indicates the preamplifier frequency range is 1 to 30 MHz, tests indicate a much higher upper end. The preamplifier has a built-in bias tee for powering through its RF output connector and requires 11 to 16 Vdc at 40 mA.

Figure 8 ~ Antenna preamplifier with a gas-tube lightning protector on its input. This photograph was taken just before the coaxial connections were sealed. The amplifier is mounted in a weatherproof enclosure along with type N-F bulkhead connectors and internal RG-316 coaxial cables. C-clamps were used rather than drilling the 1 in thick steel plate on the center piling at the antenna. Note the eye-bolts and turnbuckles in the corners of the plate that support the antenna center structure. Image © 2019 W. Reeve

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4. Receiver Common Equipment

The HAARP facility provided an insulated walk-in enclosure for the equipment (figure 9). The common equipment (figure 10) consists of a Lenovo M710q (Tiny) desktop PC running Windows 10 Pro, CyberPower Systems CP1350PFCLCD uninterruptible power system (UPS) rated 1350 VA and 810 W, Aviosys IP Power 9258TP web-controlled power switch, Netgear BR500 network router and two 2RU rack panels, one for the power supplies and one for the bias-tee and RF splitter. The latter enclosure also houses the Callisto and associated up-converter, which are described in the next section.

Figure 9 ~ Panorama showing the TCI-540 antenna (towers in the background), Radio JOVE antenna (to the immediate left of the small enclosure with the gable roof) and equipment enclosure for the observatory (larger of two enclosures on the right). The skid-mounted, walk-in, observatory equipment enclosure is 8 x 9 ft (2.4 x 2.7 m) and houses all common equipment and receivers. The two smaller enclosures are not related to the observatory. The blue man-lift on the left was used during erection of the Radio JOVE dual dipole antenna. Image © 2019 W. Reeve

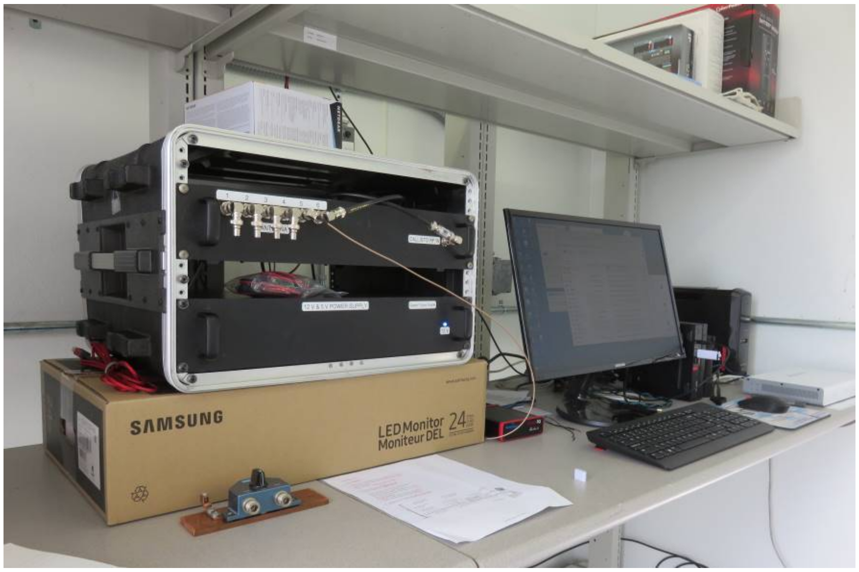

Figure 10 ~ Common equipment. The 19 in equipment rack on the left, shown on a temporary cardboard shelf, houses the two rack panels – an RF panel on the top and power supplies panel on the bottom. The Cloud-IQ receiver is barely visible to the immediate right of the cardboard shelf. The Radio JOVE receiver, discussed later, is on the upper shelf and not visible in this picture. The PC, monitor, keyboard, mouse, UPS, web power switch and router are on the right. The equipment enclosure has plenty of shelf space and includes a temperature-controlled heater for winter and cooling fan for summer. Image © 2019 W. Reeve

After the initial installation in June I noticed the voltage provided by the local rural electric cooperative to the HAARP facility occasionally ran as high as 137 Vac at the equipment enclosure. The normal voltage should be 120 Vac ± 10%. To reduce electrical stress on the equipment, in early August I installed a 250 VA Sola model 63-23-125-4 constant voltage power conditioner, which provides a nominal 120 Vac output voltage for a very wide range of input voltage. This model originally was designed to be hard-wired. For additional flexibility and to minimize the work required at the site, I modified the power conditioner to include a power cord with plug, 15 A duplex receptacle, on-off switch, input circuit breaker, RC filter (snubber) on the output receptacle and power indicating lamp.

Like the power conditioner, the UPS has proven essential at HAARP. Except when the Ionospheric Research Instrument (IRI) is in-use during a research campaign, the facility is powered by the local rural electric cooperative. The facility is near the end of a long distribution line and throughout the summer electric service interruptions occurred a few times per week, most lasting a few seconds but some lasting up to 30 min. Internet service is provided through optical fibers by the local rural telecommunications cooperative, but there were a few service interruptions each week, usually lasting only a few seconds but one lasted 6 hours. Some of the internet service interruptions were coincidental to electric service interruptions but not all, and some may have been due to network maintenance by UAF-GI staff. I noticed that the number of electrical and internet interruptions decreased as the summer lightning season came to an end.

The RF common equipment is installed in a 2RU rack panel. The main components are two bias-tees (one to power the TCI-540 antenna preamplifier and the other for future use) and 6-way RF splitter (figure 11). The RF output of the bias-tee connects to the splitter that, in turn, connects to type BNC-F bulkhead connectors on the front RF patch panel for distribution to the receivers. I had extra space in the panel so I installed the Callisto and up-converter in it. All internal RF connections are RG-316 coaxial cable. I used PowerPole chassis mount connector blocks for power connections to the bias-tees, Callisto and up-converter.

Figure 11 ~ RF enclosure. The bias-tees (an Advanced Receiver Research DC-INJ and a Mini-Circuits ZNBT-60-1W+) and splitter (Mini-Circuits ZFSC-6-1) are on the left side of the enclosure; the ARR bias-tee is active. The Callisto instrument is the extruded aluminum enclosure in the middle and the UPC232 up-converter is on the right side. Two 3 dB attenuators are connected to the Callisto RF input to control the transmission level point. Power connectors are on the rear panel behind the Callisto and converter. This image was taken in the shop prior to moving the unit to the HAARP site. Image © 2019 W. Reeve

The 2RU power supply rack panel presently includes a 13.5 Vdc, 150 W ac-dc power supply and 5 Vdc, 25 W dc-dc converter (figure 12). The ac input to the 13.5 Vdc power supply is conditioned by an EMI filter mounted adjacent to it. I also installed filter capacitors on the output of each power supply. Each power supply has a dedicated PowerPole bus for load connections; the 13.5 Vdc bus connects to a PowerPole RigRunner 4012 (12 port) power distribution panel mounted on the back of the enclosure. The power distribution panel allows easy connection of additional loads without opening the enclosure. The panel has enough space for future power supplies that may be required for additional output voltages.

Figure 12 ~ Power supply enclosure. All ac connections are insulated from accidental contact. The 13.5 Vdc power supply is the larger unit in the middle and the 5 Vdc converter is to its right. A bag of spare fuses for the external distribution panel is taped inside. An 8-position power distribution block is immediately behind the 13.5 Vdc power supply and a 4-position block is behind the 5 Vdc converter. The top of the 4012 power distribution panel is visible at the outside-rear of the enclosure. A blue 13.5 V power indicating LED is mounted on the front panel. This image was taken in the shop prior to moving the unit to the HAARP site. Image © 2019 W. Reeve

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5. Callisto & Up-Converter

The Callisto system was commissioned on 13 June, but the Sun has been quiet and no radio bursts have been detected as of this writing (October 2019). Initial problems were encountered with severe radio frequency interference from the nearby DigiSonde transmitter but most of the interference disappeared during investigation by the HAARP staff at the DigiSonde site. The DigiSonde, or Digitally Integrating Goniometric IonoSonde, is a model DPS4D manufactured by Lowell Digisonde International. It is far more advanced than the analog ionosondes typically used for ionospheric radio propagation research, but interference from it is a well-known problem. The DigiSonde transmitter antenna is about 800 m east-northeast of the TCI-540 antenna. Since it operates in the same frequency band as the observatory receivers, at least some RFI is unavoidable.

The Callisto has a native frequency range of 45 to 870 MHz so a heterodyne up-converter is used for radio observations in the HF range. I use a model UPC232 up-converter, built in my shop, which has an internal bandpass filter with a 10 dB bandwidth from 1.7 to 36.7 MHz (the filter is more fully described in {Reeve16-2}). The converter uses a 200 MHz local oscillator, and the output IF frequency range is the RF input frequency plus 200 MHz. The Callisto frequency configuration file is setup to tune frequencies in the range 204 to 240 MHz, corresponding to an up-converter input (or observation) frequency range of 4 to 40 MHz.

I modified the 2nd IF in the Callisto installed at HAARP to use a passband filter that is nominally 80 kHz wide (unmodified Callistos use a 300 kHz filter). This modification was made for experimental purposes. While installing the Callisto and up-converter, I attempted to field-optimize the RF levels by inserting attenuators in front of the up-converter and between the up-converter and Callisto (figure 13). The present scheme seems to work okay as shown by the spectrum view and lightcurves produced by the Callisto software (figure 14 and figure 15), but no solar radio bursts have been received to validate the scheme.

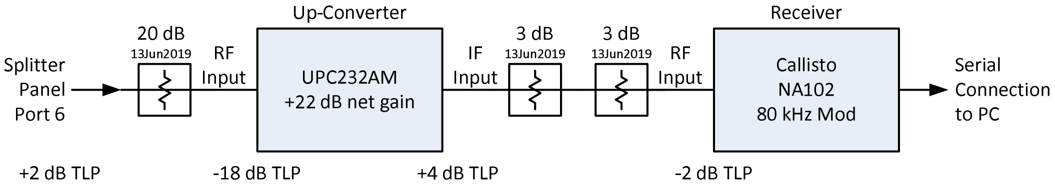


Figure 13 ~ Transmission diagram for the Callisto and up-converter installation. The attenuator values and transmission level points shown are as-of 13 June and subject to change based on additional testing. The input TLP at the antenna preamplifier (not shown) is 0 dB, and the net of all transmission path gains and losses at 30 MHz to the output of the splitter panel results in the TLPs shown here. Image © 2019 W. Reeve

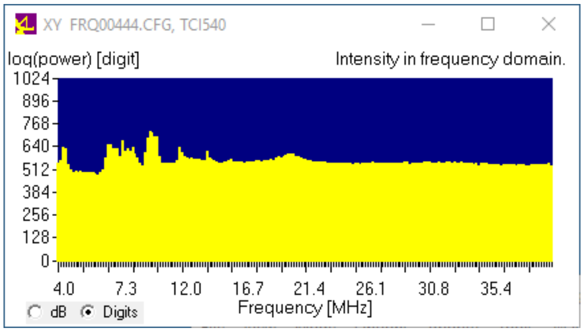


Figure 14 ~ Spectrum y(f) image taken from the Callisto software about 3 h after local sunrise on 29 August 2019. There are no significant received signals above about 15 MHz but activity is apparent between 5 and 14 MHz. The spectrum represents signals received from all directions. The view shows the logarithm of the RF input power after analog-digital conversion for the frequency range 4 to 40 MHz.

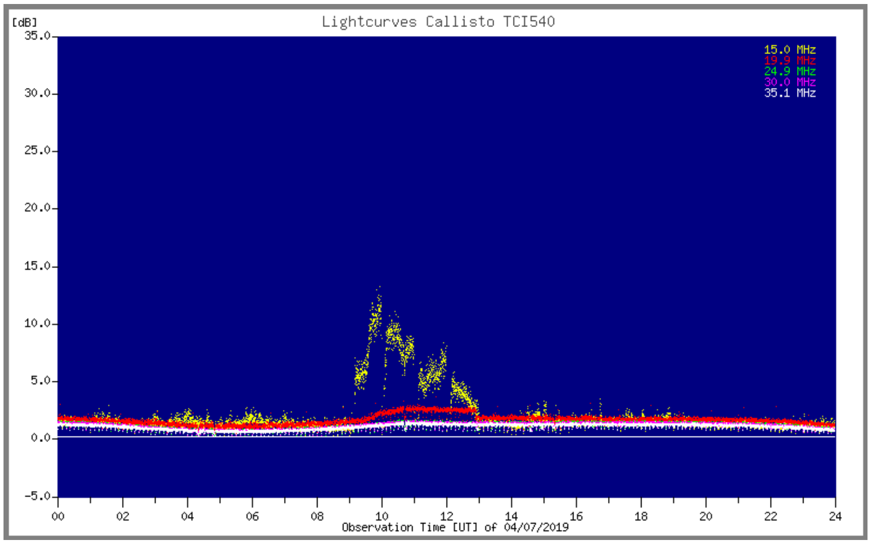


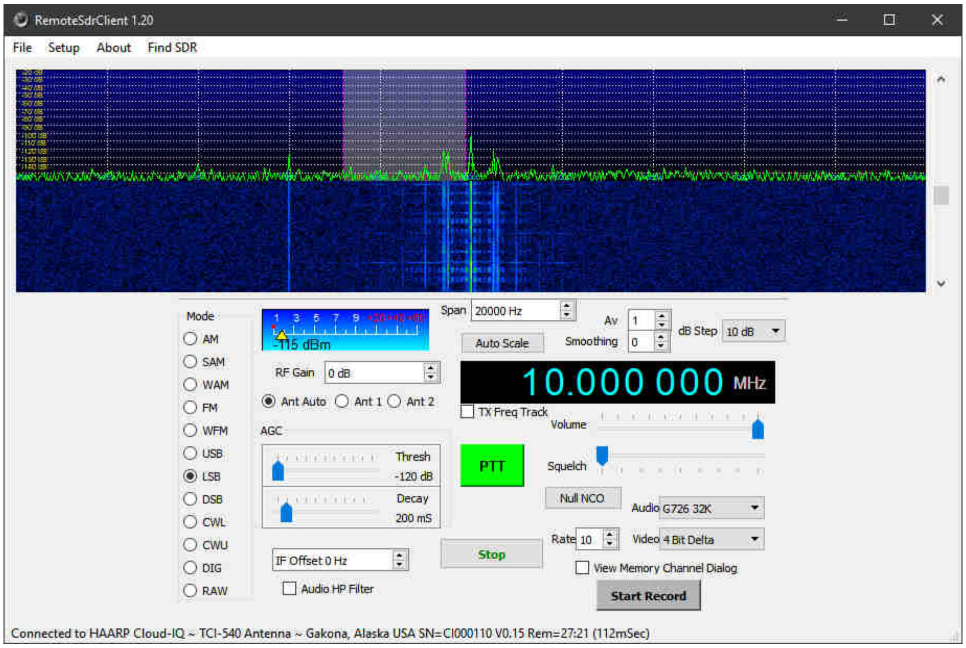
Figure 15 ~ Lightcurve y(t) image taken from the Callisto software for the 24 h period on 4 July 2019. The relative received signal power in dB is shown for five individual frequencies throughout the day. The frequencies and corresponding trace colors are given in the upper-right corner. The timescale on this plot is in UTC; local time is UTC-8 h. Note that the time-frequency stations WWV and WWVH were received quite well at 15 MHz (yellow trace) between 0700 and 1300 UTC (11:00 PM and 5:00 AM local time). Sunrise on 4 July was about 1200 UTC and sunset was about 0730 UTC.

6. Cloud-IQ SDR

The RFSpace Cloud-IQ has a frequency range of 9 kHz to 56 MHz with 1 Hz resolution (figure 16). The receiver at HAARP is set to the *Cloud* mode, which allows users to connect to it through the worldwide web. The connection is setup by the SDRanywhere server operated by RFSpace. I previously had not used the Cloud mode in actual service, so this installation gave me a chance to learn more about it. I did note some limitations, which are discussed later.

As of this writing I have the time limit for a remote connection set to 30 min and the connection is not password protected. These settings may change in the future. To access the receiver, users need to run an application called RemoteSdrClient (figure 17) for PC or Mac systems or SDRanywhere for Android systems. Spans from 1 kHz to 10 MHz may be displayed on a remote connection. The receiver may be operated in all common modulation modes including AM, Synchronous AM, FM, SSB, CW and a couple of Phase-Shift Keying (PSK) modes. Another available mode is called *RAW*, which is discussed below.

Figure 16 ~ Full scale image of Cloud-IQ front panel. The receiver requires 5 Vdc. It has two antenna input connectors on its rear panel that can be provisioned for specific frequency ranges between 9 kHz and 56 MHz. At HAARP the full range is setup on one connector (ANT1). Image source: RFSpace



RemoteSdrClient 1.20

Mode: ○ AM ○ SAM ○ WAM ○ FM ○ WFM ○ USB ● LSB ○ DSB ○ CWL ○ CWU ○ DIG ○ RAW

-115 dBm

Span 20000 Hz

Av 1

Smoothing 0

dB Step 10 dB

RF Gain 0 dB

● Ant Auto ○ Ant 1 ○ Ant 2

10.000 000 MHz

☐ TX Freq Track

Thresh -120 dB

Decay 200 mS

IF Offset 0 Hz

☐ Audio HP Filter

Audio G726 32K

Rate 10

Video 4 Bit Delta

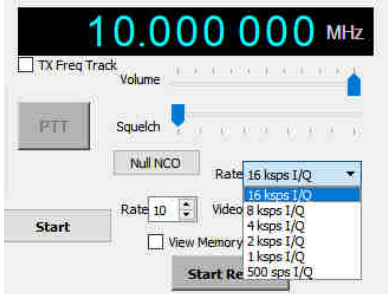
☐ View Memory Channel Dialog

Connected to HAARP Cloud-IQ ~ TCI-540 Antenna ~ Gakona, Alaska USA SN=CI000110 V0.15 Rem=27:21 (112mSec)

Figure 17 ~ RemoteSdrClient screenshot showing a live connection between Anchorage and the Cloud-IQ receiver at HAARP. The center frequency is set to WWV and WWVH on 10 MHz and the displayed span is 20 kHz. The demodulation mode is set to lower sideband (LSB). When in *Cloud* mode, the receiver internally processes the I-Q signals and sends compressed spectra video and compressed audio to the RemoteSdrClient. This image was captured at about 0330 UTC (7:30 PM local) on 19 August 2019 as the signal strength was decreasing for the day.

In the *Cloud* mode, the receiver's I-Q (In-phase and Quadrature-phase) data are preprocessed by the receiver and sent through a web connection to a user client as a compressed spectra video and audio stream. The video and audio compression methods can be selected by the user. The preprocessing greatly reduces the digital bandwidth required on the internet connection and is useful when the user only needs to listen to the demodulated audio and view the live spectra. When the demodulation is setup this way, the audio data stream can be recorded in the WAVeform audio file format (.wav) for later analysis but only relative spectra amplitudes are displayed during playback. RemoteSdrClient has no provisions for viewing or playing its own WAV files but the SpectraVue application can be used for this purpose (SpectraVue is supplied with all RFSpace SDR receivers). The files sizes are determined by the selected audio compression method. The playback display in SpectraVue indicates the original center frequency but the displayed audio spectrum is offset from the center frequency. The recovered audio in a few test recordings sounded correct.

The Cloud mode also supports sending a raw I-Q data stream (RAW mode) to the user's RemoteSdrClient. In this mode, it is the demodulated I-Q data that is sent, not the actual audio. Several sample rates are supported from 500 samples per second (sps) to 16 ksps (figure 18), but the RAW mode also has some operational limitations discussed below. The preprocessed RF spectra also can be sent simultaneously as a video stream or turned off completely. When in the RAW mode, a separate window shows a scatter plot of the relative amplitude and phase of the demodulated I-Q data (figure 19).



10.000 000 MHz

☐ TX Freq Track

Rate 16 ksps I/Q

Rate 10

Video

☐ View Memory

Figure 18 ~ Partial screenshot of the RemoteSdrClient main window showing the drop-down list of RAW mode I-Q sample rates. Other controls visible here are the Rate scrollbar, which controls the speed of the live spectra waterfall (if setup to be viewed), and a button for adjusting the Numerically Controlled Oscillator (NCO) to remove (null) any dc bias at the center frequency.

Figure 19 ~ Screenshot of the *RAW I/Q Scatter Plot* window with Rate set to 16 ksps. The window is divided into four quadrants corresponding to 0-90°, 90-180°, 180-270° and 270-360° phase. A perfectly stable signal would be displayed as a single pixel at a fixed amplitude and phase. However, because of variations as the signal propagates through the ionosphere, the displayed signal will vary, often wildly. Shown here is a weak signal from WWV/WWVH at 10 MHz with varying amplitude and phase in the first quadrant. The displayed trace was slowly rotating counter-clockwise with a period of about 0.5 second when the screen was captured. The rotation could be slowed or stopped by tuning the receiver center frequency 1 or 2 Hz below the actual transmitted signal frequency, indicating a small receiver oscillator error.

The RAW I-Q stream can be recorded as WAV files for later viewing and analysis or processed by another application. The recorded file size depends on the selected sample rate. When operated in the RAW mode, the shaded area around the center frequency on the spectrogram, which normally indicates the demodulation bandwidth, always shows 500 Hz. Also, when the recorded I-Q data stream is played back, the displayed signal bandwidth always is 500 Hz regardless of the sample rate, and the displayed span is limited to the sample rate; for example, if the sample rate is 16 ksps – the highest available – the displayed span is 16 kHz and the signal occupies only 500 Hz. My tests showed that RAW mode recordings at the 500 and 1000 sps rates would not play properly in SpectraVue (I did not try any other application) and that absolute signal amplitudes are not preserved at the other sample rates.

Because of the limitations noted above for the various modes, the remote recordings from the Cloud-IQ in Cloud mode are usable only for narrowband reception and not usable for wideband solar radio reception and analysis.

The RemoteSdrClient allows control of the receiver's built-in attenuator, which is indicated as RF Gain in the control section of the window. Selectable values are 0, –10 and –20 dB. The receiver is connected to one of the RF splitter output ports, where the Transmission Level Point is +2 dB at 30 MHz. The Cloud-IQ attenuator should be set to 0 dB except when very strong signals are being received. Even at lower frequencies, where the TLP is higher due to lower transmission line loss, the attenuator probably is not needed except for very strong signals. For example, the TLP is only about 3 dB higher at 15 MHz.

7. Radio JOVE Receiver & Dual Dipole Antenna

The Radio JOVE receiver is a direct conversion receiver with a nominal operating frequency of 20.1 MHz (tunable approximately ± 150 kHz) and a detection bandwidth of about 3.5 kHz. Its audio output is connected to the PC soundcard and processed by Radio SkyPipe II software. The soundcard is set to 12 kHz, 16-bit stereo. So that remote users can access the live data, the Radio SkyPipe II is set to *Server* mode. An RF-2080 Noise Calibrator is inserted between the antenna and the receiver. The Radio JOVE installation was arranged and coordinated with UAF-GI by Chuck Higgins of the Radio JOVE Project. He traveled to the site specifically to install the receiver and antenna and for public outreach purposes. I assisted with the hardware and software setup, which uses the same PC and power supplies as the other systems.

The antenna installation work was done by the HAARP on-site staff, who placed the dual dipole in the east-west direction so that its main beam would be pointed southward. The two dipoles were erected on 20 ft aluminum masts recovered from a now-decommissioned project. The masts were fastened to concrete barriers and guyed with non-conductive strand to concrete block anchors (figure 20). The dipole wire elements and RG-59 transmission line components were taken from a standard Radio JOVE kit previously sent to the site. A 135° phasing cable (3/8-wavelength, or 12.12 ft of RG-59 coaxial cable) was placed between the southern dipole and the RF combiner as indicated in the antenna manual for a dipole height of 20 ft.

Figure 20 ~ Radio JOVE dual dipole antenna setup at HAARP. Concrete barriers were placed by HAARP staff in the east-west direction to support the four antenna masts. The masts were inserted in the ends of the barriers and then guyed with non-conducting strand to concrete block anchors (not visible in this image). The shed immediately behind the antenna houses a GPS antenna and receiver unrelated to this project. The equipment enclosure for the receivers and common equipment is in the middle-background. Image © 2019 W. Reeve

The coaxial cables from each dipole feed-point normally are 1-wavelength long (32.32 ft of RG-59). However, because of the height of the dipoles, the original cables drooped to the combiner and potentially could be hooked by moose antlers as they roam through the area. Therefore, 1/2-wavelength extensions (16.16 ft of RG-59) were added later so that the cables could be secured to vertical non-conductive center masts and placed in ground-laid plastic pipe for physical protection.

Figure 21 ~ Weatherproof cable entrance protector panel mounted on the back of the equipment enclosure. The panel is a DX Engineering model DXE-UE-2P Utility Enclosure with three protectors mounted on the supplied aluminum plate. The left protector is a Tii Technologies model 212FF75F225-31 that uses type F-F connectors for the Radio JOVE antenna and receiver. The other two protectors, both Citel model P8AX09-N/MF, use a type N-M on the antenna side and N-F on the receiver side. The middle protector is for future connection, and the one on the right connects to the TCI-540 antenna feedline and indoor RF panel. A 6 AWG bare copper conductor bonds the panel to a ground rod. Image © 2019 W. Reeve

For protection from lightning and static build-up, the feedline from the antenna is connected to a protector in the cable entrance panel on the back of the equipment enclosure (figure 21). A LAN controlled antenna relay will be installed in the future to allow the Radio JOVE receiver to be switched between the dual dipole and the TCI-540 antenna for comparison.

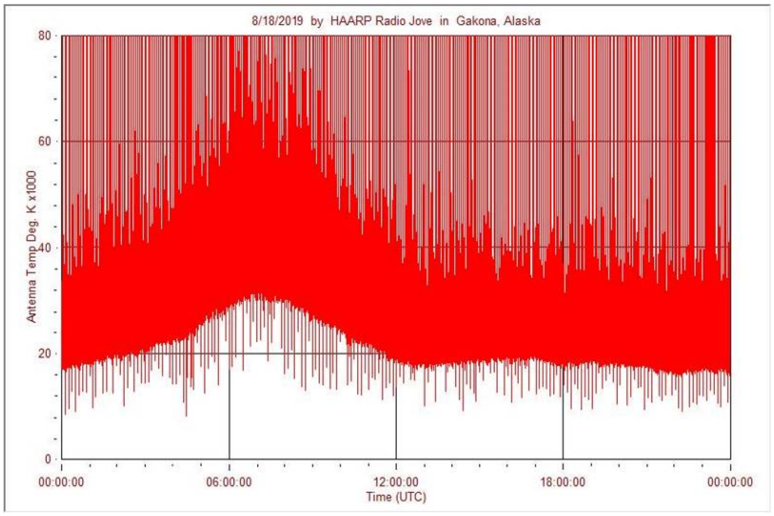


Figure 22.a ~ 24 h plot of Radio SkyPipe II raw data for 18 August 2019 showing the rise and fall of the noise floor due to the galactic radio background at 20 MHz from the Milky Way galaxy drifting in and out of the antenna beam as Earth rotates. The shape of the plot is determined by both the antenna pattern and the galactic background. The peak is around 0700 UTC. See next figure. The noisy nature of the plot is explained in the text. Note that the difference between the minimum and maximum is equivalent to only a couple dB. Plots on different days show slightly more or less variation.

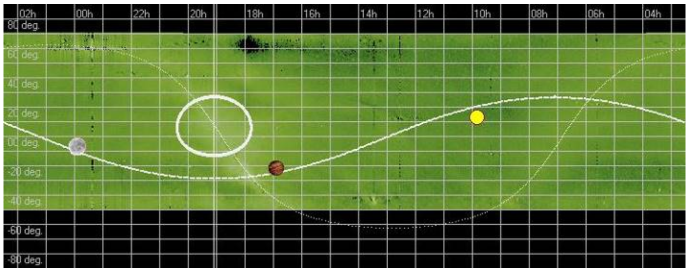


Figure 22.b ~ RadioEyes view of the galactic radio background at 35 MHz as seen from HAARP. The thicker white line is the local horizon with the Moon just rising on the left and Sun after sunset on the right. Jupiter is between the two near the horizon. The Milky Way galaxy and its increased radio background is seen as the diffuse S-shaped band and thin white line. Its peak is on the meridian, indicated by the heavy vertical white line, at about 35° elevation (the meridian is shifted left in this image). This peak corresponds to the peak at 0700 UTC in the noise temperature recorded by Radio SkyPipe II in the previous figure.

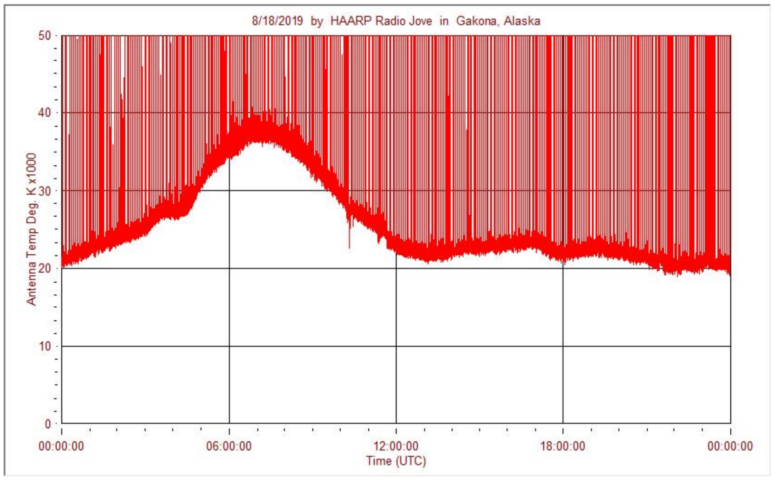


Figure 22.c ~ Same data as a. except the data has been processed by mean smoothing to reduce the noise in the baseline.

The antenna installation went smoothly because of the work done by the HAARP staff. Tests were completed on 7 August. The Radio SkyPipe II software was placed in Server mode so that it may be accessed by remote Radio SkyPipe II clients. After returning to Anchorage, I monitored the system and connected regularly without any problems. I downloaded and plotted the data for several days to see if the galactic radio background is visible, and it is (figure 22). The 24 h plots are noisy due to interference from the HAARP DigiSonde; the effects of this interference on 24 h plots can be reduced by data smoothing. The plots are much quieter for a shorter time period (figure 23).

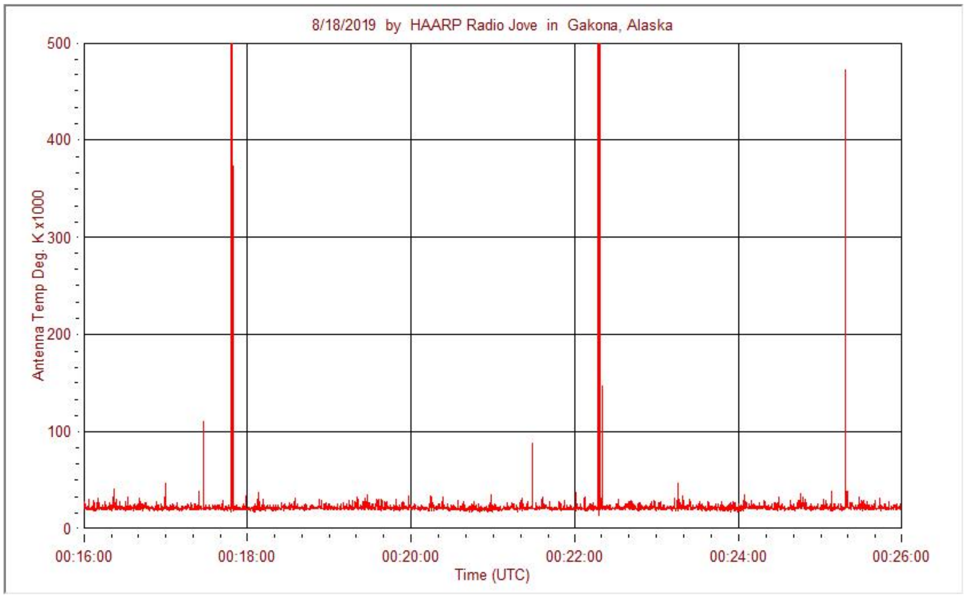


Figure 23 ~ Radio SkyPipe II plot for a 10 min period during late afternoon on 18 August 2019. Three strong pulses are visible at 0017:20, 0022:50 and 0025:50, a pattern that repeats 24 h d^{-1}. The noise baseline represents the galactic background radiation at 20.1 MHz. The effects of the interference on 24 h plots of the background radiation can be reduced by smoothing.

8. Future

I plan to install additional equipment over time to further support the space weather and radio propagation initiatives of my original proposal. In particular, an AirSpy HF+ SDR receiver, controlled by SPY server for Windows software, will be used to allow web connections to this relatively narrowband (660 kHz) SDR. Also, to further support the Radio JOVE project, I plan to install an FSX-5S switching spectrometer or a couple SDRPlay RSP2pro SDR receivers with Radio Sky Spectrograph and SDRPlay2RSS software and a 4-element terminated folded dipole (TFD) array antenna setup for circular polarizations (the existing TCI-540 provides only horizontal polarization). I also may install a Raspberry Shake seismometer and a Blitzortung.org lightning detection system.

9. Acknowledgements

This project would not have been possible without the assistance from the HAARP staff. The HAARP Program Manager approved my proposal to establish the radio observatory, and the on-site staff assisted with all aspects of erecting the Radio Jove antenna, laying the coaxial cables and protective pipes, preparing the equipment enclosure, and setting up the network connections. Also, the UAF-GI IT staff's assistance with network configurations was indispensable.

10. References & Weblinks

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[DoD] Personal communications from retired HAARP Chief RF engineer on 4 June 2019

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