Reception of SAQ Transmissions at Cohoe Radio Observatory on 1 July 2018

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1. Introduction

In early June 2018 I was notified of the annual commemorative transmissions from Sweden planned for *Alexanderson Day* on 1 July 2018. These transmissions use the historical call sign *SAQ* and are sponsored by the Alexander Association, a group of dedicated historical radio enthusiasts. The station transmits only on special occasions. I previously attempted to receive SAQ's transmissions on Christmas day 2017 at Anchorage but the local noise levels were far too high.

During that same month I installed a new loop antenna at my Cohoe Radio Observatory for monitoring VLF and LF transmissions and detecting sudden ionospheric disturbances (SID). This installation uses an SDRPlay RSP2Pro software defined radio (SDR) receiver and SDRuno software. The initial site survey and test results with this combination were quite encouraging. I decided to attempt reception of the Alexanderson Day event at CRO and was successful. This paper describes the setup and results.

2. Stations

The transmitting and receiving stations are on opposite sides of Earth but at roughly similar latitudes (table 1). Both stations are not far above sea level and are near to the ocean. The great circle path between SAQ and CRO is mostly over water and ice and passes almost directly over the North Pole (figure 1).

Table 1 ~ Transmitting and receiving station details
(AMSL: above mean sea level; AGL: above ground level; TN: true north reference)

Station	Latitude	Longitude	Elevation (m AMSL)	Antenna height (m AGL)	Distance (km)	Direction (° TN)
SAQ, Grimeton, Sweden	57° 06' 23.1" N	12° 23' 28.6" E	35	127	6870	351
CRO, Cohoe, Alaska USA	60° 22' 04.7"N	151° 18' 55.1"W	22	3.5		010

SAQ is a historical longwave communications station in Grimeton, Sweden. The transmitter currently operates on 17.2 kHz. It was built in the early 1920s and uses a motor-generator (alternator) transmitter weighing 50 tons that was developed by Ernst Alexanderson. Its original output power was 200 kW but it has been reduced to approximately 70 kW today. Typical of VLF stations, the antenna system is huge. It consists of six 127 m high towers spaced at 380 m intervals. Each tower has a 46 m long crossarm supporting eight copper conductors in a top loading arrangement. The main radiating elements are six vertical copper conductors, which provide vertical polarization to the transmitted signals. The antenna's original efficiency was about 12%, and its original radiation pattern favored the northwesterly through southwesterly to southeasterly directions [Wiklund] (figure 2). An important original communication point was New York City at a true direction of 293°, which is within the main antenna lobe. Additional station details including history and videos can be found at {SAQ}.

Note: Internet links and references in braces { } and parentheses ( ) are provided in **section 7**.

The CRO receiving station consists of an untuned 1.2 m diagonal square loop antenna and associated rotator, SDRPlay RSP2Pro SDR receiver and associated SDRuno software, twisted pair transmission line and Lenovo M910 SFF PC with Windows 10 x64 operating system (figure 3). The loop antenna was oriented north-south during the reception putting SAQ well within its ideal radiation pattern.

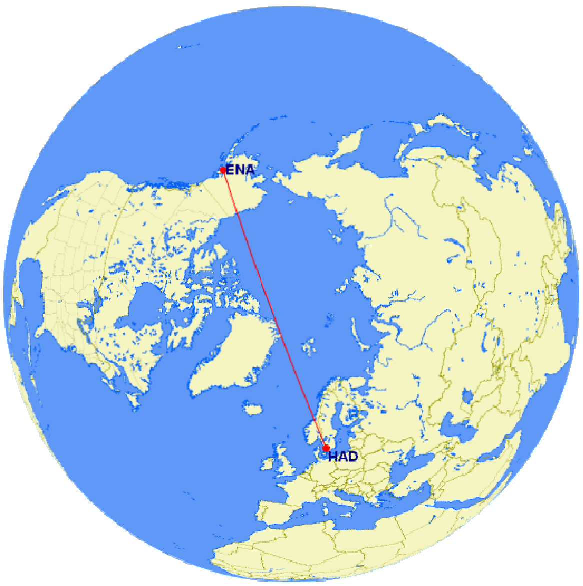

Figure 1 ~ Map of great circle path between the two station locations, a distance of 6870 km. Image produced by Great Circle Mapper {GCMap} using the airports closest to the sites: Halmstad Airport (HAD) in Sweden and Kenai Airport (ENA) in Alaska.

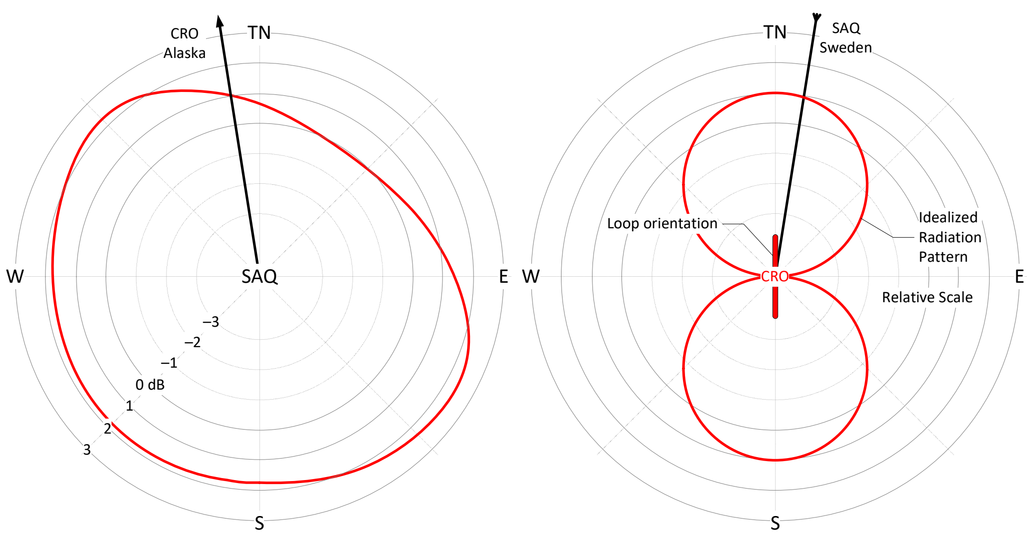

Figure 2 ~ Antenna radiation patterns. Left: SAQ antenna radiation pattern based on a plot provided by [Wiklund] from measurements in the early 1960s. More recent measurements have not been made. Right: Cohoe Radio Observatory Idealized radiation pattern for a small loop antenna.

3. Transmission and Reception

Three sets of SAQ transmissions were scheduled for Sunday, 1 July, as follows (all times in Coordinated Universal Time, UTC) {SAQSched}. All three sessions were broadcasted live and recorded on {YouTube} and all messaging used Morse code:

- 1st session tuning startup at 0815 with message transmission at 0845;
- 2nd session tuning startup at 1015 with message transmission at 1045;
- 3rd session tuning startup at 1215 with message transmission at 1245.

The transmissions at Grimeton t took place during that location's local mid- and late-morning but were in the middle of the short night at Cohoe. A solar terminator (gray line) map shows the daylight and darkness and position of the Sun at 1045 UTC (figure 4). Rather than stay up all night I setup a scheduled WAVE recording in SDRuno from 0840 to 1250 UTC and then viewed the recording later. This setup recorded an I-Q band from about 0 to 120 kHz. I was interested only in the band immediately around the transmission frequency 17.2 kHz but was limited by the sampling and decimation rates available in the RSP2Pro and SDRuno software (lowest available is 2 MHz basic sampling rate with factor 8 decimation). This recording session saved seven 2 GB Wave files (.wav) and one partial file for a total of 14.2 GB. The large amount of data was the tradeoff for unattended operation.

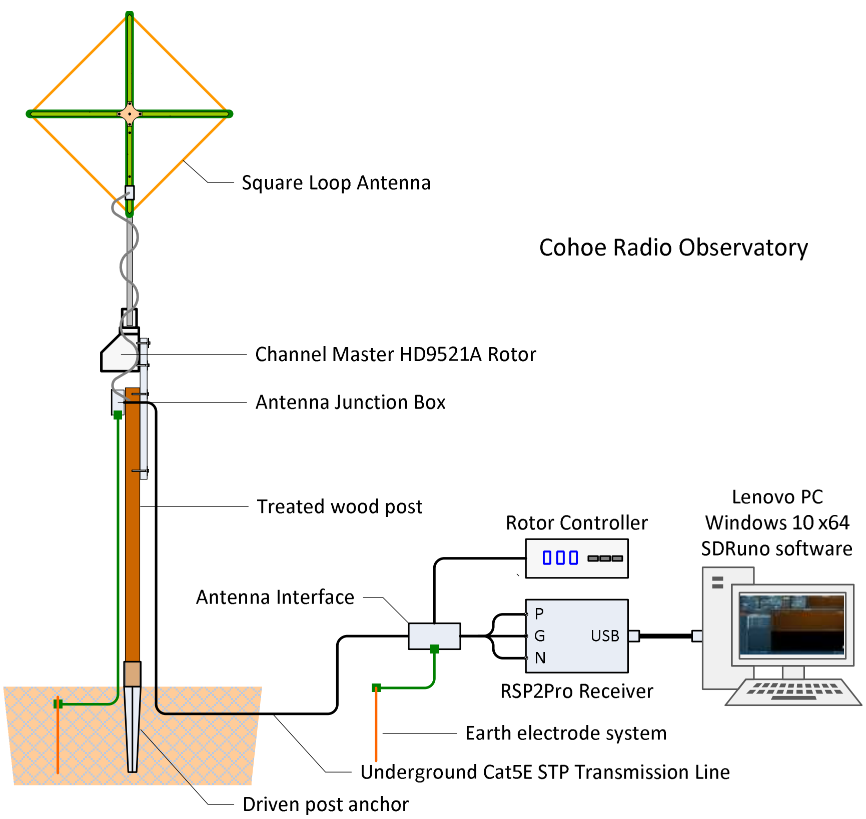

Figure 3 ~ VLF receiving system at Cohoe Radio Observatory. The shielded twisted pair transmission line is installed in liquid-tight flexible non-metallic conduit and buried just below the ground surface. The antenna is connected to the receiver's 1000 ohm *HI Z* balanced input through an interface that includes 100 kohm resistors to control common mode currents. The antenna is connected to 1 pair of the STP cable and the rotator is connected to the remaining 3 pairs.

Loop diagonal: 4 ft (1.2 m)
Loop area: 7.9 ft^2 (0.733 m^2)
Windings: 64 ±1 turns of 18 AWG coated magnet wire
Inductance: 12.3 mH
Self-resonant frequency: 46 kHz
Tuning: None
Antenna height: 11.5 ft (3.5 m) above ground level

4. Propagation

The Earth-ionosphere waveguide mode is the likely mechanism by which the SAQ radio waves propagate to CRO. The antennas at the transmitting and receiving stations are coupling probes in the waveguide. In the waveguide mode both multi-hop skywaves and ground waves are important to propagation. At VLF, Earth's surface and the ionosphere's D-region are considered to form a concentric spherical waveguide – the surface conductivity is high and the ionosphere's D-region has a sharp boundary for efficient low-angle radio wave reflections. The waveguide mode produces a signal attenuation rate of about 1.5 to 3 dB/1000 km (figure 2-20, {Navalex}). Using this attenuation rate on a path length of 6870 km, the *basic* transmission loss is a low 10 to 21 dB.

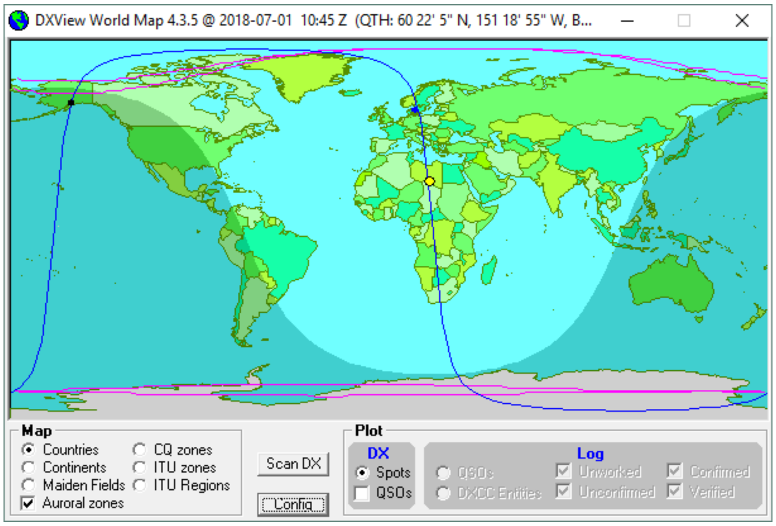

Figure 4 ~ Solar terminator map showing the great circle propagation path (blue line) between CRO in Alaska and SAQ in Sweden at 1045 UTC. The station's locations are indicated by blue dots. Local times at the stations corresponding to UTC are 2:45 AM at CRO and 12:45 PM at SAQ. The Sun's location is indicated by the yellow circle, which is coincidentally located directly on the long path between the two stations. This image was produced from DXView, a component of the DXLab software {DXLab}.

Many factors affect the *overall* transmission loss, which is made up of the basic and other losses. The other losses include transmitting and receiving antenna efficiencies, radiation patterns and local Earth losses, which determine how radio energy is coupled into and out of the Earth-ionosphere waveguide. On the SAQ to CRO propagation path, the transitions between land, water and ice and the steep inclination of Earth's magnetic field at northern latitudes make analysis of the path very complicated. The enormous transmitting power and large antennas and counterpoises of present-day VLF stations indicate that additional losses involved in these types of transmissions are very high.

For a first order estimate of the received signal level from SAQ, I used figure 2-25 in {Navalex}, which is a plot of received electric field strength versus frequency for various daytime seawater path distances with 1 kW transmitted and 80 km ionosphere height. The field strength shown for a 4000 mi (6400 km) path distance at 17 kHz is about 38 µV m^{-1}. Assuming the SAQ antenna efficiency still is 12% and transmitter power is 70 kW, the radiated power is about 8 kW, and the estimated received signal strength is approximately 8 kw x 38 µV m^{-1} kw^{-1} = 300 µV m^{-1}. The calculated effective height of the CRO loop antenna at 17.2 kHz is about 0.019 m (see {Reeve18} for calculations). The effective height translates the field strength to an open circuit voltage of 6 µV at the antenna. The 1300 ohm antenna impedance at 17.2 kHz and 1000 ohm receiver input impedance form a voltage divider and only about 43% of the antenna open circuit voltage reaches the receiver input, or 2.4 µV. At 1000 ohms input impedance, this is equivalent to an input power of about –112 dBm.

5. Reception Analysis

Playback and analysis of the recorded Wave files in SDRuno showed a weak but easily recognizable signal in the spectrum display and waterfall (figure 5). I could hear the Morse code messages, particularly the letter S, at various times, but the signals were too weak to understand other characters with any certainty. The signal itself was easy to see on the Main Spectrum display and I could enhance it by using FFT averaging. The main disadvantage of FFT averaging is that it smears the signal in time and reduces the displayed time resolution. However, for my purposes of simple detection, the FFT averaging helped me confirm the signal; my goal at the time did not include displaying the separation of individual Morse characters. Note the power displayed in the Main Spectrum window (–107 dBm) is on the same order as the calculation above, probably a coincidence.

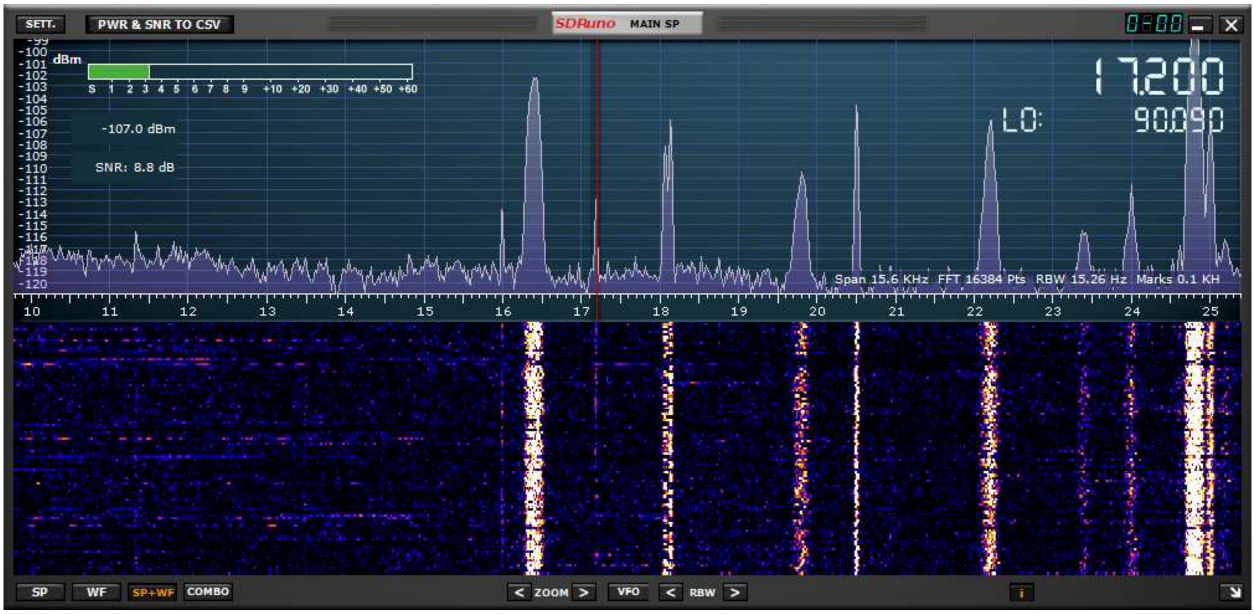

Figure 5 ~ Received spectrum at CRO in the frequency range from about 10 to 25 kHz with tick marks at 100 Hz intervals. The receiver is tuned to 17.2 kHz which places a red vertical cursor in the spectrum at that frequency. In this case, the signal under the cursor is station SAQ at 17.2 kHz. The other signals seen in the main spectrum are VLF transmitters for submarine communications. At various times of day I can see up to twelve of these transmitters in a 10 kHz wide band centered on 20 kHz. The signal at 24.8 kHz is the strongest and its 1.2 MW transmitter (call sign NLK) is in Washington State only a couple thousand kilometers away from Cohoe. The two signals that bracket SAQ are JXN at 16.4 kHz in Norway and a Russian VLF transmitter at 18.1 kHz.

I also examined the intermediate frequency (IF) spectrum, and the signal can be easily seen at 700 Hz offset (figure 6). There is an offset because I operated the receiver in *Zero-IF* mode with CW demodulation. The CW offset (equivalent to a *beat frequency oscillator*, BFO) was set to 700 Hz, and CW transmissions at 17.2 kHz will be demodulated in the receiver IF and displayed as 700 Hz tones. Note that AM and SSB modes would display the same signals without any offset.

Given that the SAQ transmitter is a motor-generator set whose frequency is determined by its rotational speed, the frequency of the received signal was remarkably stable. Over the short term the stability probably is determined by the rotational inertia of the very heavy rotor in the transmitter. However, I did note some drift in the received signal frequency on the order of ±25 Hz over the course of the transmissions (figure 7).

According to a report posted about five weeks after the commemorative transmissions, over 300 stations all around the world reported receiving the signal {SAQReport}. Only five stations in the USA, including my station at Cohoe, Alaska reported receiving the signal. About one-third of the receiving stations were in Germany and, surprisingly, only 25 stations were in Sweden. I sent in a reception report to the Alexander Association and within a couple weeks I received a QSL card in return (figure 8).

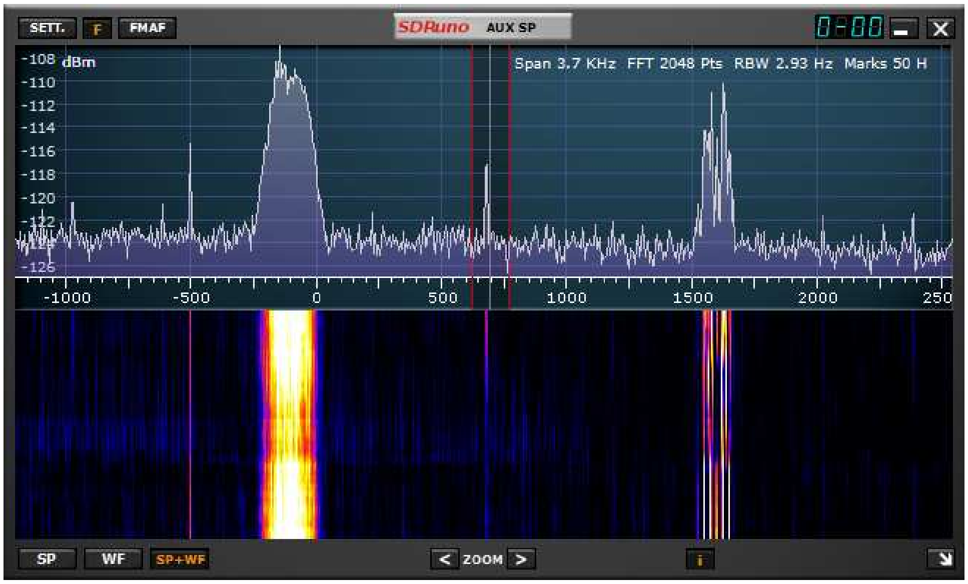

Figure 6 ~ Received IF spectrum at CRO with a resolution bandwidth slightly lower than 3 Hz. The SAQ signal is 5 or 10 Hz below the ideal value of 700 Hz (CW offset setting) and is bracketed by red cursors in the center of the IF spectrum. The cursors indicate the CW filter edges, which affect the demodulated signal fed to the PC sound system but have no effect on the displayed spectrum. The total displayed span is 3.7 kHz with the receiver frequency of 17.2 kHz centered at 700 Hz on the IF frequency scale. The frequency scale tick marks are at 50 Hz intervals. The strong signals to the left and right of the SAQ signal are JXN at 16.4 kHz in Norway (displayed at a frequency of –100 Hz, or 800 Hz below the receiver frequency) and a Russian VLF transmitter at 18.1 kHz (displayed at +1600 Hz). Note the difference in modulation of the Norwegian and Russian transmitters. A receiver spur or birdie is visible at –500 Hz, equivalent to a receiver frequency of 16.0 kHz. The RSP2Pro shows such spurs at 8 kHz intervals when the receiver is set for low frequencies.

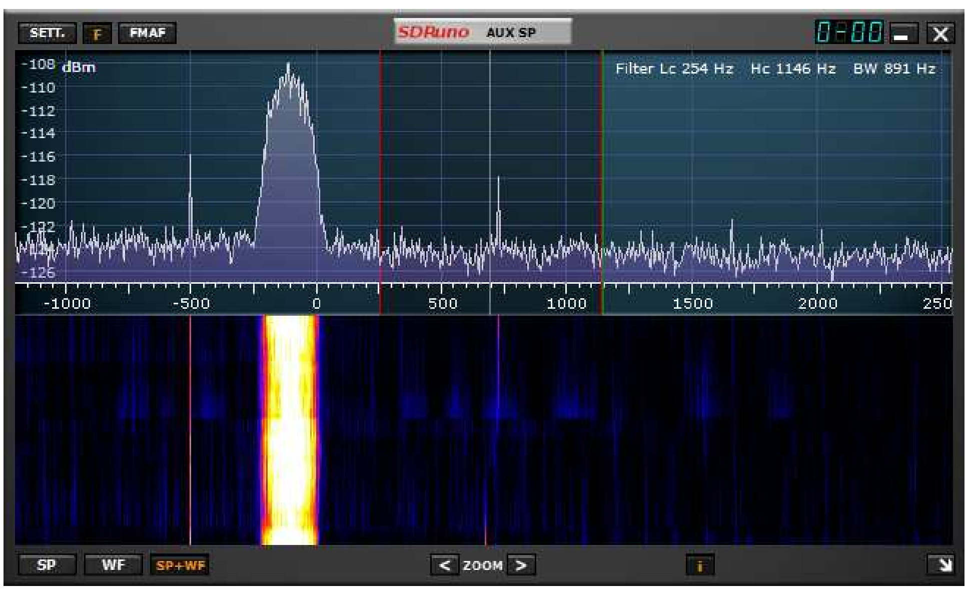

Figure 7 ~ Received IF spectrum at CRO showing frequency drift of the SAQ signal. This spectrum image has the same settings as previous figure except the CW filter edges (red cursors) have been widened. The SAQ signal has moved approximately 25 Hz above the 700 Hz CW offset. Note that in the waterfall below the spectrum the SAQ signal trace wanders while the spur at –500 Hz and signal at –100 Hz do not drift. Also, note that the Russian station previously seen at +1600 Hz offset has temporarily disappeared; this is common for this station, which turns on and off at irregular intervals.

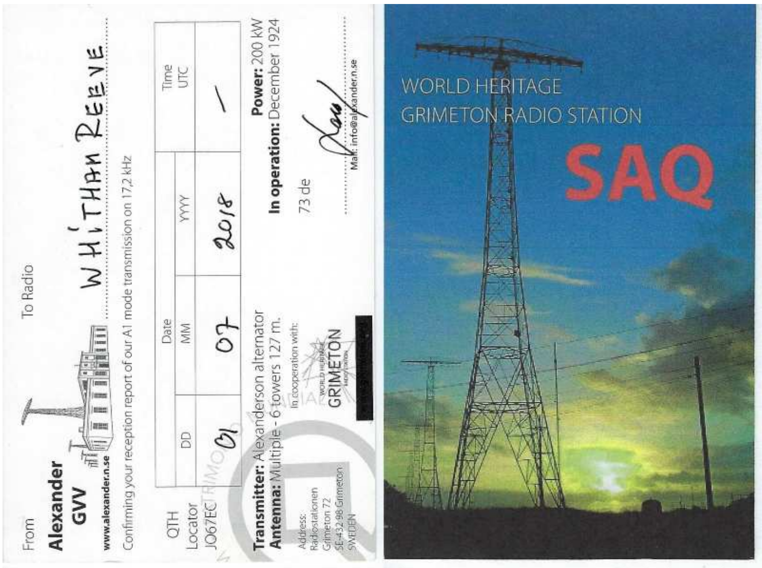

Figure 8 ~ SAQ QSL card from 1 July reception report (scan of back and front). The front panel is a picture of some of the SAQ antenna towers

6. Discussion

The ambient VLF noise levels at CRO are low enough to allow reception of weak signals such as from station SAQ. Using FFT averaging enhances the displayed spectrum but does not improve the audio demodulation. Received signal strength could be improved by using a loop antenna with larger area or more windings. Either or both would improve the conversion of the signal's magnetic field variations to an electrical signal detected by the receiver. However, more windings increase the winding capacitance, which lowers the loop resonant frequency unless special winding techniques are used. For narrowband single frequency reception, tuning the loop by resonating it with a variable capacitor would significantly increase the system sensitivity. Other possibilities for antenna improvement are different loop designs and a loop antenna connected directly to a balanced preamplifier located at the loop itself.

As for receivers, the RSP2Pro is not the only SDR whose frequency range extends down to VLF. Others include the AirSpy HF+ {AirSpy} and the RFSpace SDRs {RFSpace}. These other receivers have only unbalanced 50 ohm RF inputs so a balun would be required to interface with the twisted pair transmission line that I used. Many analog VLF up-converter designs are available as kits or ready-built (for example, {NooElec} and {WB9KZY}). The loop antenna may be connected directly to a PC soundcard through transient voltage suppressors (soundcards are not designed for connection to outdoor equipment such as a loop antenna so some means of protection must be used). Alternately, a preamplifier could be used with the soundcard as in the SARA SuperSID monitor {SuperSID}. Using a soundcard as a VLF receiver requires a more general type of software for signal analysis such as Spectrum Lab {SpecLab} or SAQrx {SAQrx}, the latter being designed specifically for SAQ reception. If the goal is to only detect and demodulate the signal, then no external software is needed. In this case, the operating system's built-in record and playback functions can be used.

7. References and Weblinks

{Navalex} VLF, LF, and MF Communication Systems, NAVALEX 010,113, Naval Shore Electronics Criteria, August 1972, available at: http://www.navy-radio.com/manuals/shore-vlf.htm

{Reeve18} Reeve, W., Square VLF Loop Antenna, 1.2 m Diagonal ~ Mechanical and Electrical Characteristics and Construction Details, 2018, available at: http://www.reeve.com/Documents/Articles%20Papers/Reeve_SquareLoopAntenna1.2m.pdf

[Wiklund] Private communication, Fredrik Wiklund, Alexander SAQ, 26 August 2018

{AirSpy} https://airspy.com/airspy-hf-plus/
{DXLab} http://www.dxlabsuite.com/
{GCMap} http://www.gcmap.com/mapui?P=HAD-ENA
{NooElec} http://www.nooelec.com/store/sdr/sdr-addons/ham-it-up-plus.html
{RFSpace} http://www.rfspace.com/RFSPACE/Home.html
{SAQ} http://alexander.n.se/?lang=en
{SAQReport} https://alexander.us1.list-manage.com/track/click?u=521e9c51318e4c7f70e1e6b56&id=2ed0e2a080&e=15074cc155
{SAQrx} http://dl1dbc.net/SAQ/SAQrx/SAQrx_0-98.zip
{SAQSched} http://alexander.n.se/SAQ-Forum/topic/saq-transmission-01-07-2018-2/?lang=en
{SpecLab} http://www.qsl.net/dl4yhf/spectra1.html
{SuperSID} http://www.radio-astronomy.org/node/210
{WB9KZY} http://wb9kzy.com/lfconv.htm
{YouTube} https://www.youtube.com/channel/UC-83S-l9JKD1iuhsXx3XQ3g?sub_confirmation=1

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