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FSK radio communication below 3 kHz using HAARP ionospheric excitation

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Abstract

The HAARP HF antenna array was employed to modulate overhead ionospheric currents and transmit an FSK signal below 3 kHz for communication purposes. The basic properties of the successfully observed signal at a distance of 37 km from HAARP are presented. The outcomes of the experiment showcase this method of producing lower radio frequency emissions as a viable means of communication with submarines or in underground mines, with possible ameliorations in bit rate or modulation type.

1. Introduction

Generation of radio signals below 30 kHz by modulated heating of the ionosphere has been investigated since 1974, usually for the characterization of the ionospheric and plasmaspheric environment. The most powerful facility used for such activities is the HAARP (High Frequency Auroral Research Program) facility in Gakona, Alaska, delivering up to 3.6 MW of radiated power within 2.9-9 MHz radio frequency range and with the capabilities for active beamforming and beam steering. The HAARP facility allows the radio illumination of the auroral electrojet – natural currents appearing in the ionosphere at certain latitudes – which significantly enhances the radiated low frequency radio emissions that are modulated on the HF carrier [1, 2]. HAARP-generated low frequency emissions have the reported range up to 4400 km [3] and were registered outside of the Earth-ionospheric waveguide by numerous spacecraft (e.g. DEMETER [4] or Cluster [5]).

For the cases where the electrojet is negligible (e.g. on the medium latitudes), nonlinear ionospheric interactions with incoming radio signals can manifest themselves in increased signal attenuation for lower frequencies and cross-modulation (i.e. the Luxembourg-Gorki effect) [6] – as the ionized layer absorbs one signal and can transfer its modulation to another one that is reflecting from, or propagating close to, the same layer. [7].

It would be therefore possible to hypothesize that the sufficiently strongly excited and modulated ionosphere / electrojet – strongly enough to cause the observable generation of the radio emissions below 30 kHz, could be effectively used as a viable mean of transmitting useful information [2, 8]. This frequency range is used for radio communication with submarines and mines but its exploitation is, unfortunately, limited by the required physical sizes of the radiating structures and maximum voltage limits [9, 10]. A natural 'ionospheric antenna system' would allow these requirements to be bypassed – the emissions would be radiated from the upper layers of the atmosphere, excited by a significantly smaller and strategically safer array of high frequency dipoles with active beamforming which also allows a certain choice (within practical limitations) of the illuminated area.

A pioneering experiment of using HAARP to generate QPSK-modulated signals was carried out in 2012 at the fundamental re-emission frequency of 1510 kHz (ITU: Ultra Low Frequency / ULF band, 0.3-3 kHz [11]) with numerous harmonics reaching up to VLF band (3-30 kHz) [11]. Different bit rates (100-800 bps) and investigation of the BER (Bit Error Rate) parameter were explored [12]. It was shown that the higher bit rates result in a significant widening of the signal's bandwidth, greatly reducing the SNR.

In the experiment described here, a different type of angular signal modulation has been chosen for the ionospheric illumination [13], in order to demonstrate effective information transmission without a significant band dissolution / with the highest possible SNR and to provide an initial experimental prequel to the signal modulations used almost exclusively in the VLF band (e.g. the Minimum Shift Keying [14]).

2. Experimental FSK transmission

The experiment using the HAARP antenna system was carried out on 7th November 2023 between 05.45.00 and 05.59.30 UT, with the transmitter set for 2.8 MHz carrier operating in X-mode (circular right-handed polarization) vertical Double Broad Beam. With these parameters the HF beam at ionospheric altitudes has diameter of approximately 50 km [15]. The carrier wave frequency was chosen in order to expose the carried modulating signal to the maximized absorption in the lower ionospheric layers to enhance the effect of the demodulation.

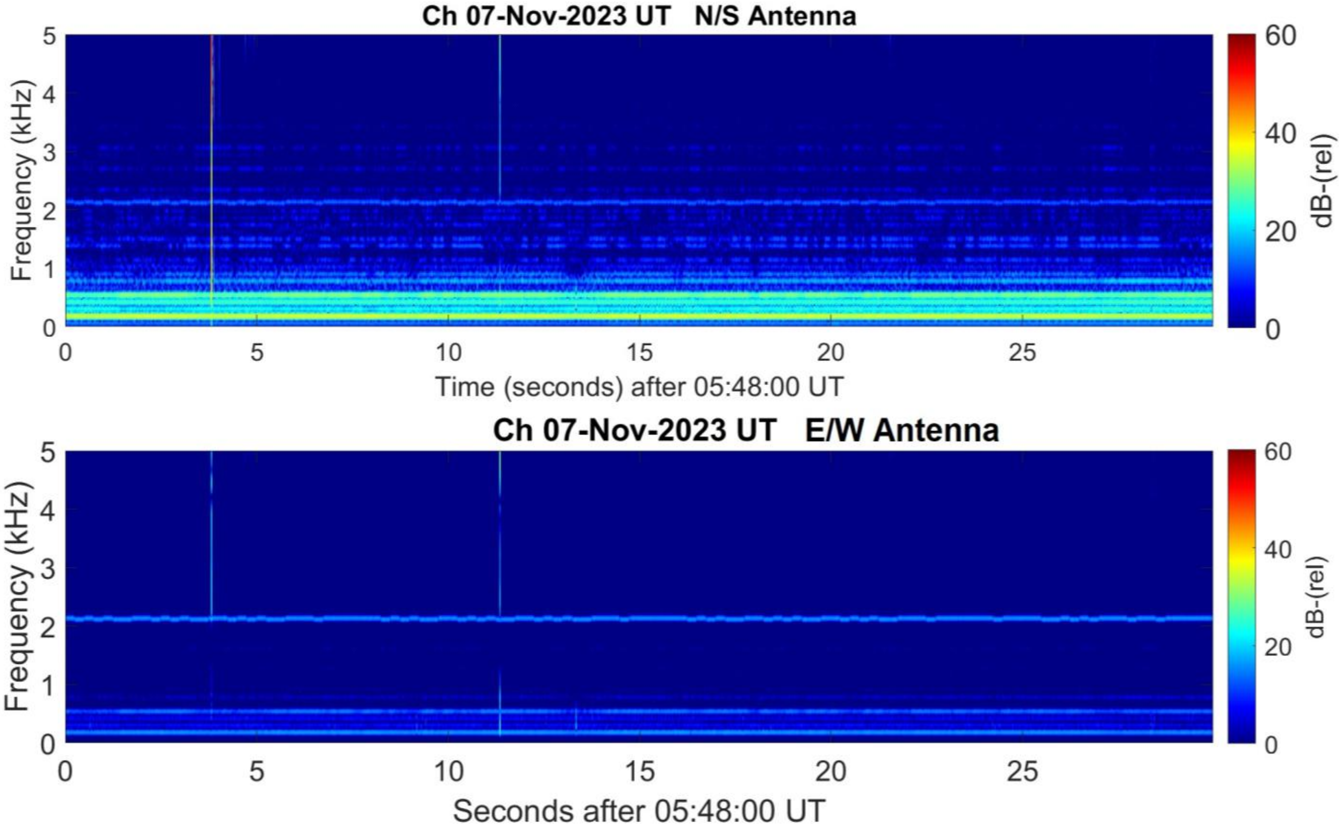

Figure 1. The spectrograms for the ionospherically re-emitted FSK signal at 2115/2135 Hz, recorded at Chistochina, 37 km away from the HAARP facility. The data were recorded on two orthogonal magnetic field antennas.

The modulating signal consisted of a Frequency Switch-Keyed (FSK) message on 2.115 kHz and 2.135 kHz (20 Hz separation), composed of a continuous (without spacers) string of Morse-encoded letters. The string was repeated for a total duration of 60 seconds.

3. Recorded signals

The HAARP's transmission has been received and recorded in the receiving station in Chistochina, USA, 37 km away from the HAARP facility operated by Univerisity of Florida. The magnetic field strength of the re-emitted signal has been recorded on two directions – N/S (north-to-south) and E/W (east-to-west). Figure 1 presents the spectrograms of the transmission for both directions for the first part of the FSK message. Two frequencies of the message can be easily noticed, with reduced (e.g. exhibiting a similar frequency shifting) harmonics, which is one of the main observations distinguishing this experiment from the QPSK one [12]. The observable harmonic content of observed HAARP generated ionospheric ULF/VLF signals generally depends on the ionspheric conditions. Stronger generation is usually associated with stronger harmonics. The conditions on the day of the experiment were judged to be favorable for ULF/VLF generation. The composition of the FSK message is continuously maintained, with no spectral artifacts produced during the frequency switching, allowing a stable and unequivocal reception and decoding.

The message had the decoded form of looped letter configuration:VVVVVVVVVCQCQCQDEAXOAXLAXOAXLAXOAXL100YRSPOLVLF19232023, designed to commemorate the 100th anniversary of the Babice Transatlantic Radio Station in Poland. The measured bit rate of the transmission reached 10.9333 bit/s (41 WPM; one order of magnitude higher than predicted for the Sanguine transmitting system [16] and in the same order of magnitude for short-range VLF systems employing mechanical rotating-magnet antennas [17]) and definitely did not exhaust the possibilities of increase.

The amplitude (in normalized units) was measured as values integrated over 30 seconds for both receiving antenna directions for both FSK frequencies and is shown in Table 1. The differences between the subsequent amplitudes have their origin in the fact that the higher frequency contained more continuous wave than the lower frequency (asymmetrical composition of the encoding) and that over the E/W direction the existing auroral electrojet was the major contributor to the ionospheric re-emission (being modulated by the incoming HAARP signal).

Table 1. Comparison of amplitudes integrated over 30 s for subsequent receiving antenna directions.

f [Hz]	N/S amplitude [-]	E/W amplitude [-]
2115	1.78246	2.47424
2135	2.58716	3.72829

6. Conclusions

The presented experiment, similarly to the one from 2012 by Jin et al., [12] has successfully proved that the utilization of the ionospheric re-emission of radio signals below 30 kHz is a viable method for communication. In this transmission however, a narrower and more conventional modulation method was employed, similarly to actual submarine communication signals, maximizing the signal-to-noise ratio by the minimization of the required bandwidth. The narrowing of the bandwidth would also allow a better penetration of the water and ground layers. The experiment can be considered as a prequel to the employment of the Minimum Switch Keying (MSK) modulation for the ionospherically-re-emitted radio transmissions, allowing the employment of this method to submarine- and mine communication with higher bit rates.

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