Structure of Signal Received by Passive Ionospheric Sounding in the HF Band at the Location of Timisoara, Romania

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***Abstract*—The ionospheric channel is time-variant and is affected by several factors such as variable attenuation, fading, modification of the polarization plane of waves, Doppler shift and nonlinearities. Therefore, communication channels through the ionosphere are subject to a high degree of variability. Nevertheless, communication through the ionospheric channel presents interest due to the modest requirements for infrastructure. In this paper, we report records of signals that are received by antennas in the HF band in Timisoara, Romania and we investigate the structure of these signals. This study is motivated by the future deployment of HF communication links for emergency situations.**

Keywords—ionospheric sounding; HF band; Fourier analysis; time-frequency; correlation

I. Introduction

The ionosphere is situated at altitudes of 50-1000 km above the sea level and consists of several layers of gas that is ionized by solar and cosmic radiation and collisions with particles that are incident from outer space. While the plasma created in this way is penetrated by electromagnetic waves from the microwave frequency range, allowing for communication with satellites, it bends down waves emitted from ground that have frequencies below a maximum one belonging to the High Frequency (HF: 3-30 MHz) region of the spectrum. The bended waves travel back towards the Earth and can be received at different locations, situated at large distances from the emitter. Communication channels can be established in this way, needing only basic equipment (antennas, transmitter and receiver) and no other infrastructure [1].

Waves travel from the emitter to the receiver by one or several reflections on the ionosphere and ground. Propagation modes that stem from several reflections on different layers of the ionosphere are also possible. Since a receiving antenna gathers waves that have propagated through different distances, the signal is subject to fading. Attenuation occurs mainly by absorption in the lower layer of the ionosphere (called the D layer) and by reflection on the ground. Since the D layer is situated at low altitude, it vanishes at night due to the decrease of solar radiation. Consequently, attenuation is smaller after sunset than before. Displacements of gas masses in the ionosphere are responsible for Doppler shifts occurring when waves reflect at interfaces of the moving gas layers. Ionosphere is an anisotropic medium. Therefore, polarization of electromagnetic waves can be modified by propagation. Nonlinear effects and background noise also affects transmitted and received signals [1-3].

The propagation conditions in the ionosphere change throughout day and season and vary with latitude [4]. All these factors seem to rule out the use of the ionospheric channel as a medium for reliable transmissions. However, the simple, basic equipment needed for establishing a link explains the existing applications of communications in the HF band in radio broadcasting for geographical regions that lack infrastructure or when infrastructure cannot be accessed, in establishing point-to-point communication links in the operational fields where military troops are deployed, in emergency situations, in amateur radio communications etc.

The present work is part of a project aiming to implement a communication system in the HF band that is intended to be used in emergency situations in Romania, for the case when the existing communications infrastructure is not available. The proposed solution relies on spread-spectrum techniques. In order to design the communication links, it is important to asses the propagation conditions, the number and types of signals that occupy the spectrum and to evaluate the level of background noise and interference. We report here results obtained by monitoring the ionospheric channel for noise, interferers and other signals, including "opportunistic" ones [5]. The acquisitioned signals are analyzed by means of time-frequency representations, Fourier transform and correlation. In the next section, we briefly describe the receiving equipment and present and analyze acquisitioned signals acting as noise and interferers. In Section III, we report and describe other signals that were found and we outline possible applications. Conclusions and future work are presented in the last section.

II. Receiving Equipment and Acquisitioned Signals

A system composed of two antennas (Harris RF 1936 and Diamond WD 330 J), an NI USRP-2950R, 50 MHz – 2.2 GHz Dual RF Transceiver SDR (Kintex – 7, 410T FPGA) and GPS

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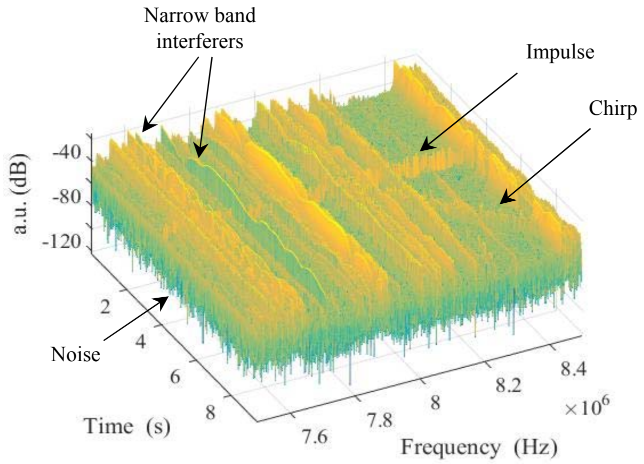

Fig. 1. Time-frequency representation of a signal received on February 3, 2016 at 09:10:16 (GMT+2). Sampling frequency: 1 MHz.

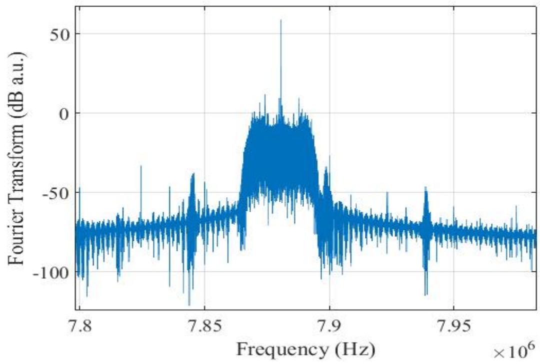

Fig. 2. Detail of spectrum of the 7.88 MHz component of the complex signal represented in Fig. 1.

Clock, an extension LFRX USRP Daughterboard (DC – 30 MHz) and a PCIe – MXI Express Interface Kit for USRP RIO has been mounted and tested as described in [6]. The system operates in the GNU radio environment and provides received digital complex signals (I and Q components) in a frequency band that is specified by the user, who can also select the sampling rate. The GPS coordinates for the location of antennas are (45.747370 N, 21.225863 E).

Previous reports on measurement campaigns carried on in various parts of the world show that noise an interference in the HF band consist of three types of signals: narrow-band interferers (modulated sine waves), impulsive noise and Gaussian noise, which originates from galactic, atmospheric and man-made noise [6,7].

Several signal acquisitions have been performed in various days in 2015 and 2016. The lengths of the recordings are of the order of 10 seconds. Since signals are non-stationary, a convenient way to visualize their contents is to rely on time-frequency representations. We have used a time step of P=2000 samples, N=1024 – point FFT and rectangular window, which gives best performance for this application [8]. Note that the number of samples effectively used is below 60% of the total number of samples. This reduction is motivated by the large amount of data that needs to be processed in a reasonable interval of time. All signal processing operations have been performed in the base-band (including positive and negative frequencies, since both I and Q components of the signal were available). However, the frequency axes in the representations display the true frequency.

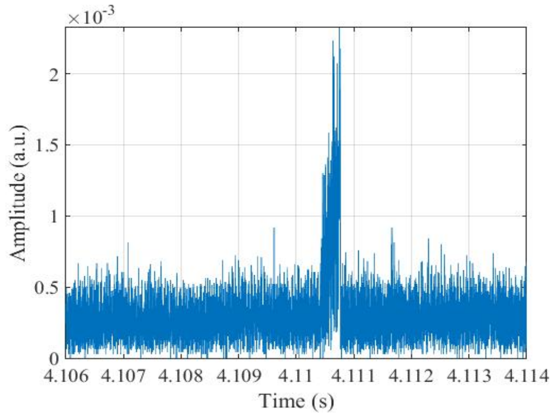

Fig. 3. Time domain representation of the impulse from Fig. 1.

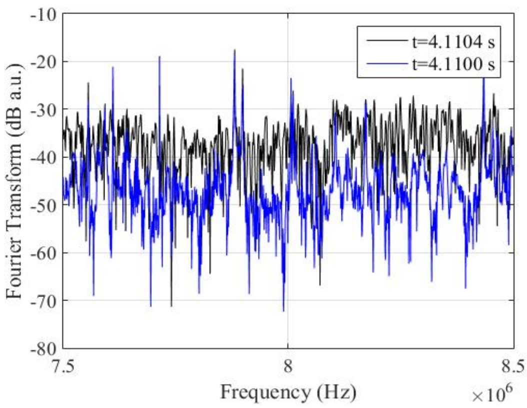

Fig. 4. Short-time spectra.

As an example, the time frequency representation of the signal received on February 3, 2016, at 09:10:16 (GMT+2) is presented in Fig. 1. The signal has been recorded for approximately 8.4 seconds, and it has been sampled with an effective sampling rate of 1 MHz. The spectrum of the signal is centered around F_s=8 MHz.

The surface in Fig. 1 reveals the presence of all three types of noise and interferences. Furthermore, large variations in the amplitudes of the received signals can be noticed, illustrating the variability of the ionospheric channel. The narrow-band interferers consist of modulated carriers that are information bearing signals for other spectrum users but which might affect communication in our case. The FFT spectrum of the complex narrow-band signal of approximately 7.88 MHz is represented in Fig. 2. The signal has been separated from the rest by digital filtering with an FIR filter with 500 weights and linear phase.

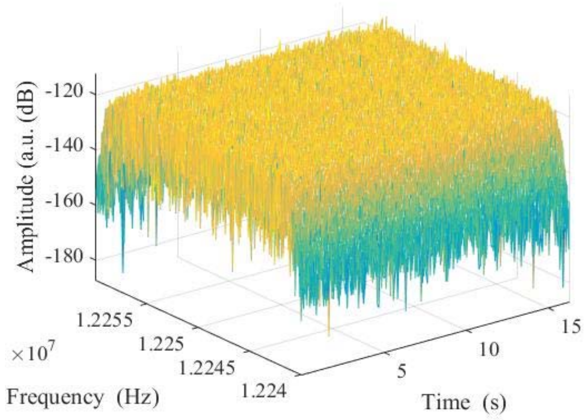

Fig. 5. Time-frequency representation of noise. The signal has been acquired on March 2, 2016, at 15:56:40 (GMT+2). Sampling frequency: 20 kHz.

Fig. 1 also shows the presence of a short duration and wideband signal, namely an impulse, whose origin is unknown. The time domain representation of the impulse (Fig. 3) reveals its short duration (about 5ms) and the presence of oscillations within its structure. The presence of the impulse can also be visualized by means of the short time Fourier transforms (1024 points) whose magnitudes are reported in Fig. 4. The wideband impulse determines an increase in the mean level of the spectrum. Impulses have occurred in many other recordings we have made. However, the measured bandwidths of the impulses have not been as large as the one in this example, in general.

The probability distribution (PDF) of noise is an important input for the design of a communication channel. This PDF is generally assumed to be Gaussian. The experiments and statistical analysis in [7] confirms this assumption, while [2] states that the pdf resembles a Bi-Kappa distribution.

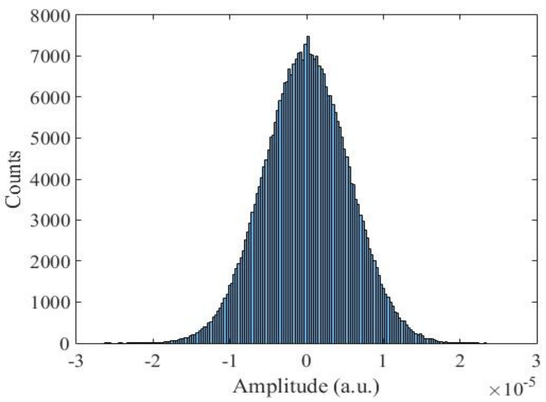

Fig. 6. Histogram for a bandpass filtered version of the signal in Fig. 5.

We have performed a statistical analysis on an acquisitioned signal that did not contain interferers in its frequency band, whose time-frequency representation is displayed in Fig. 5. The sampling frequency was 20 kHz. We have split the bandwidth in 8 equal intervals and filtered the signal with a filter bank made of FIR filters with 300 taps and linear phase, centered on the intervals. The resulted set of 8 signals can be used for statistical analysis, which will be subject for future work. We report here the PDF for the output of the fifth filter (counted in ascending order from the lowest central frequency), in Fig. 6. A chi-square goodness of fit test performed on this signal indicates that data are a random sample from a normal distribution with a 5% significance level.

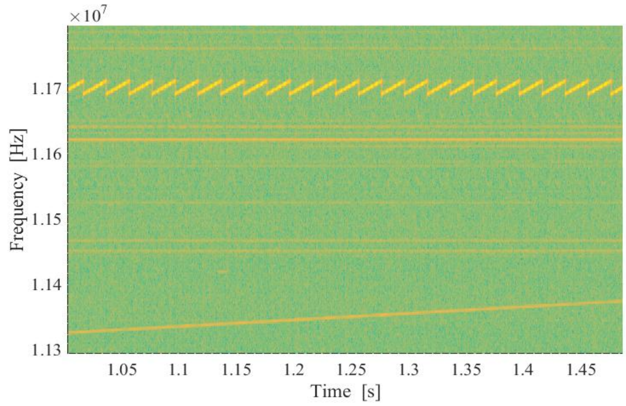

Fig. 7. Time-frequency representation of a signal containing a saw-tooth pattern frequency modulated carrier. Signal acquisitioned on June 29, 2016, 10:40:47 (GMT+3). Sampling frequency: 2 MHz.

III. Other Signals

Two other types of background signals, which do not fit into the categories presented in Section II have been acquired.

The first one is a frequency modulated carrier. The modulator is a periodic saw-tooth signal having a period of 20 ms (fundamental frequency of 50 Hz), Fig. 7. The origin of this signal could not be traced down and it has been observed only in the course of measurements performed at the time reported in Fig. 7.

The second signal is a wide-band chirp, Fig. 8, that can also be noticed on Figs. 1 and 7. Investigations have shown that this signal is emitted by the Cyprus ionosonde station [6, 9]. The Cyprus ionosphere sounding station broadcasts two chirp signals, denoted Cyprus1 and Cyprus 2, which are intended to be used for assessing the state of the ionospheric communication channel. Cyprus 1 sweeps the frequency range from 0 to 30 MHz with a rate of 100 kHz/s, giving a total transmission time of 5 minutes. For the first 2 MHz the station is quiet, so that only the 2-30 MHz band can be received. The transmission is initiated with a bias of 3'55" from exact multiples of 5'and last for 5' (the swept range divided by the sweep rate). Cyprus 2 lags by 5" with respect to Cyprus 1.

Chirp sounders are widely used for assessing the state of the ionosphere. The received signal can be processed by image-processing related techniques, by mixing and filtering, or by correlation techniques inspired from radar [8-12]. The last two methods rely on the knowledge of the transmitted signal. Since exact GPS time of emission and parameters of this signal are known, the emitted chirp can readily be reconstructed at the receiver location.

In order to demonstrate the use of correlation techniques, we have selected 13 blocks of 5000 samples (5 ms) of the reference signal and made the correlation with the received signal. In Fig. 9, the mean frequencies of the blocks are represented on one of the horizontal axes, and the time lags on the other horizontal axis. The results of correlation are displayed on the vertical axis. The surface in Fig. 9 indicates that the chirp visible in Fig. 8 is Cyprus 2. It also indicates that Cyprus1 is equally present, even if unnoticeable in Fig. 8. The time difference between the two signals has the correct value of 5 seconds, as results by dividing the frequency difference between the two frequencies of maxima that correspond to a given lag by the sweep rate of 100 kHz/s.

This procedure will be used for assessing various modes of propagation and Doppler shifts. However, for this purpose, correlation must be performed on a finer scale.

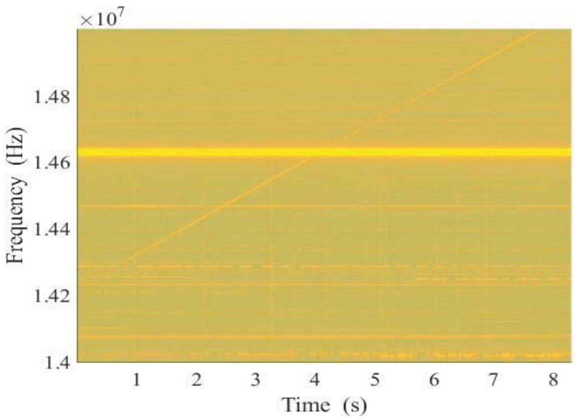

Fig. 8. Time-frequency representation of a signal containing a wide-band chirp and narrow-band interferers. Signal acquisitioned on September 27, 2015, 18.18.41 (GMT+2). Sampling frequency: 1 MHz.

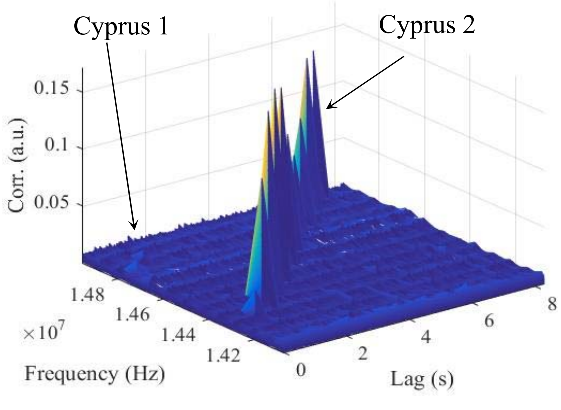

Fig. 9. Correlation with the reference of the signal in Fig. 8.

IV. Conclusions

We have analyzed the structure of the signal received by passive ionospheric sounding at the location of Timisoara, Romania. Measurements revealed the presence of noise and interferers whose parameters are similar to those obtained after measurement campaigns performed in other parts of the world. Narrow band interferers and impulsive noise have been identified and analyzed in time, frequency and time-frequency domains. Statistical analysis of a record of background noise revealed a Gaussian structure. However, this conclusion remains to be confirmed by a more sustained measurement campaign that will be subject of future work.

We have also identified the presence of signals with periodic structure: a frequency modulated carrier by a 50 Hz saw-tooth modulator and chirp signals emitted by ionosphere sounding stations. We have reported the result of a correlation analysis of the chirp signals. This technique will be used in future work for assessing the presence of propagation modes and Doppler shifts.

Acknowledgment

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References

[1] R. E. Collin, Antennas and Radiowave Propagation, Ch. 6, New York: McGraw-Hill, 1985.

[2] J. Giesbrecht, R. Clarke, D. Abbott, "Am empirical study of the probability density function of HF noise", Fluctuation and Noise Letters, Vol. 6, No. 2, pp. 117-125, 2006.

[3] M.S. Sodha, S.K. Mishra, S.K. Agarwal, "Nonlinear propagation, self-modulation, and Faraday rotation of electromagnetic beams in the ionosphere", IEEE Trans on Plasma Science, vol. 37, no. 2, pp. 375-386, 2009.

[4] D. V. Blagoveshchensky, M.A. Sergeeva, "Impact of the auroral ionosphere on HF radio propagation ", General Assembly and Scientific Symposium, 2011 XXXth URSI, 13-20 Aug., Istanbul, pp. 1-4, 2011.

[5] K. Khoder, R. Fleury, P. Pagani, „Monitoring of Ionosphere Propagation Conditions using Opportunistic HF Signals", The 8th European Conference on Antennas and Propagation (EuCAP 2014), 6-11 Apr., The Hague, pp. 2697-2701, 2014.

[6] C. Balint, A. De Sabata, "Ionospheric Propagation Investigation in Western Romania – An Experimental Approach", Bul. St. Univ. Politehnica Timisoara, Trans. Electron. Comm., vol. 60(74), no. 2, pp. 14-17, 2015.

[7] .J. Lemon, C.J. Behm, "Wideband HF noise/interference modeling Part II: higher order statistics", US Department of Commerce, NTIA Report 93-293, 1993.

[8] A. Bartlett, M. Gallagher, M. Darnell, "Extraction, Analysis and Interpretation of Digital Ionograms", IEE Int. Conf. HF Radio Syst. Tech., Conf. Publication, 4-7 July, pp. 278-282, 1994.

[9] G.G. Vertogradov, V.G. Vertogradov, V.P. Uryadov, "Oblique chirp sounding and modeling of ionospheric HF channel at paths of different lengths and orientation", Int. J. Geomagnetism and Aeronomy, vol. 7, GI 2002, pp. 1-18, 2007.

[10] M. Hagenbucher, J. Fulcher, "Noise removal in ionograms by neural network", Neural Comput. & Applic., vol. 6, pp. 165-172, 1997`.

[11] P.C. Arthur, P.S. Cannon, "ROSE: A high performance oblique ionosonde providing new opportunities for ionospheric research", Annali di Geofisica, vol. 37, no. 2, pp. 135-144, 1994.

[12] P. B. Nagaraju, E. Koski, T. Melodia, "A Software-defined Ionospheric Chirpsounder for HF Propagation Analysis," in Proc. of HF Nordic Conference, Faro, Sweden, August 2010.