A NEW SOUNDING SYSTEM FOR HF DIGITAL COMMUNICATIONS FROM ANTARCTICA

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1.- Introduction

Since the Antarctic Treaty was signed in 1959, Antarctica is a continent where only scientific activities are allowed. Many bases have been installed, where scientists and technicians live mostly during the Antarctic summer, while few bases are prepared for being operative during the Antarctic winter. Voice and data communication with the *mother country* is achieved via satellite and using the HF band. Communication with geostationary satellites is not always possible from the poles, so skywave ionospheric radiocommunications are a good and inexpensive alternative for voice and data. The bitrate of current HF radiomodems has increased significantly from 75 bps to 9600 bps through a standard 3 KHz channel. However, the channel performance in terms of delay spread, Doppler spread, and SNR of such a long link is quite unknown.

In this way, our Radio Communications Group, with previous experience in wideband modulations through the HF channel [1], is developing a new project, named SANDICOM (**S**ounding System for **An**tarctic **Di**gital **Com**munications), with two main goals. First, to measure the most significant parameters needed for the modem design, that is, SNR, delay spread and Doppler spread. Second, to implement a new radiomodem specially designed for skywave communications from Antarctica. The aim of the project is to achieve the maximum bitrate and channel availability with the minimum power consumption.

During the last winter, a new sounding system between the Antarctic Spanish Base in Livingston Island (62.6S, 60.4W) and Observatori de l'Ebre in Spain (40.8N, 0.5E) was installed by our group. The length of the path is 12.700 Km, so the number of hops is at least four or five, while only one hop is usually observed in most of the radiolinks found in the literature [2], [3]. Moreover, disturbances associated with the equatorial belt and the auroral region have to be taken into account, and the number of available ionosounders along the path is not very high.

The aim of the first campaign was to study the performance of the HF channel with no specific hardware, so standard HF transceivers have been used with a 3 KHz channel bandwidth. During the following campaigns, a new sounder based on a digital platform using FPGA, ASIC and high speed A/D/A converters will be installed. Similar to the work in [4], the RF signal will be fully generated by software, so any frequency, bandwidth (up to 100 KHz) and modulation might be chosen.

In this paper we introduce the system and some preliminary results for the 3 Khz channel. A complete description of the hardware and the tests being performed is found in sections 2 and 3. Simulations with PropLab® helped us to identify the different measured paths of the channel impulse response. The comparison between measurements and simulations is made in section 4. Finally, the conclusions and further work for the second campaign using higher bandwidths are pointed out.

2.- Hardware description

The system used to probe the channel is a low power ionospheric sounder based on commercially available equipment such as HF transceivers and a spectrum analyzer. It provides information of doppler spread, multipath, absolute signal strength and SNR in a 3 Khz bandwidth. GPS ensures coarse time synchronization between emitter and receiver. Channel characteristics are obtained in non real time mode after extensive use of digital signal processing techniques.

The channel is characterized periodically on preselected frequencies. The waveform used to probe the channel is a BPSK signal modulated by a pseudo noise M-sequence at a chip rate of 1225 bauds.

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The experiments are performed as follows. Every hour, up to 56 configurable frequencies can be sounded in a 1 minute period. Every minute is distributed as follows:

- Around ten seconds are needed for antenna tuning.
- Ten seconds are used to send / receive a 100 watts non modulated carrier. During this period in the receiver the evolution of the envelope vs. time is recorded, and absolute signal strength is easily obtained.
- An additional interval of 10 seconds is used to send / receive a BPSK signal modulated by a M-sequence. In the receiver, this signal is used to obtain the scattering function of the channel.

The emitter block diagram of the sounder is depicted in Figure 1-a. In the Antarctic Spanish base, the sounder was placed in the top of a small hill in order to keep the skywave propagation free of obstacles at low elevation angles. As a big support for the antenna could not be considered because of special environment restrictions of Antarctica, an easy to install 7.5 meters length monopole was used. The antenna tuner assures a good impedance adaptation in the whole frequency range (SWR less than 2 from 3 to 30 Mhz).

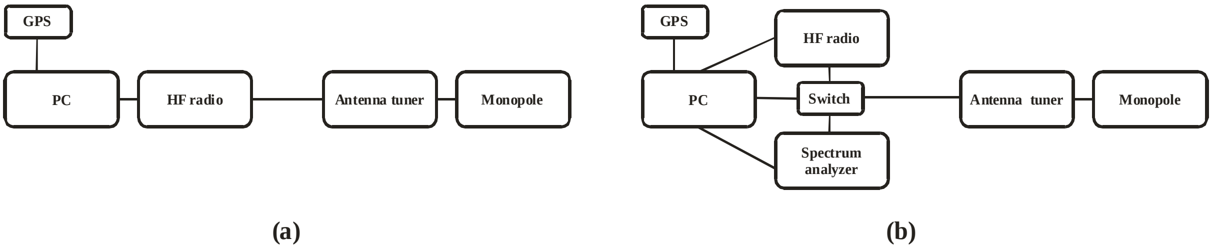


Figure 1. (a) Emitter and (b) receiver block diagram

The frequency gain of the monopole is depicted in Figure 2. The measure was performed 1 Km. far from the antenna, corresponding to 1 degree elevation angle and 5 degrees of azimuth deviation from the line of sight to Spain. Acceptable performance is shown (less than 6 dBi loss) in the 6 to 19 Mhz band. For lower frequencies the ground plane is not large enough, while for higher frequencies the monopole tends to radiate to higher elevation angles.

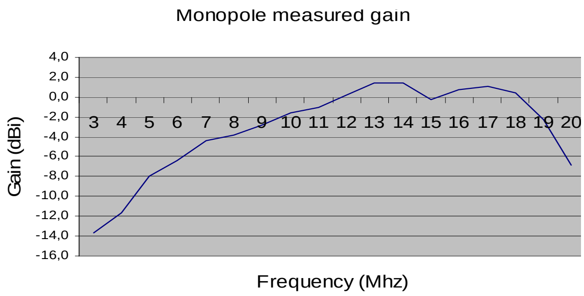


Figure 2. Monopole measured gain, in Antarctica

A PC synchronizes the transmission and offers configurability in terms of frequencies and sounding sequences. It also controls a 100 watts HF radio equipped with a good stability reference clock (0.5 ppm).

The receiver block diagram is shown in Figure 1-b. It was installed in the Observatori del Ebre (Roquetes – Spain). A monopole and an antenna tuner were also chosen because of the ease of installation and the good performance they show. The HF radio is used for antenna tuning and for M-sequence reception. The spectrum analyzer is tuned to the sounded frequency and configured with zero span and 100 Hz resolution bandwidth. It provides a time power profile during the non modulated carrier sounding period. Every minute, the PC configures the HF radio and the spectrum analyzer and records the data they provide for offline processing.

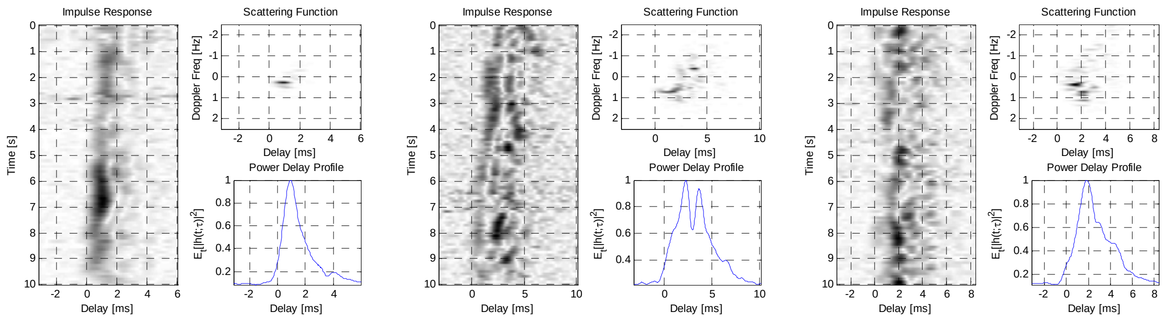
3.- Experimental results

The selected sounding signal for channel estimation was a 127 chip length M-sequence because it has good cyclic crosscorrelation characteristics. This signal was emitted during 10 sec. for a selected frequency once every hour. The sounding parameters were: delay resolution of 1/1225 = 0.816 ms (T_c = chip length); maximum delay spread of 103.7 ms ($127 \times T_c = T_{seq}$ = sequence length); Doppler resolution of 0.1 Hz (1/10s = the inverse of the analysis period); maximum Doppler of 4.82 Hz ($0.5 T_{seq}^{-1}$ = half of the sequence frequency).

The received signal during the analysis period (10 sec.) was sampled and stored at 22050 sampling rate and 16 bits/sample. This sampling frequency gives 18 samples/chip and 2286 samples/sequence in the analysis. The following processing stages were applied:

- *Doppler shift correction*: Doppler shift was detected using simple heuristic spectral analysis of the 220500 length received sequence, as the transmitted signal had zero offset and its Fourier series did not have the associated component.
- *Channel estimation:* The baseband signal was correlated with the sounding sequence giving an estimation of the channel impulse response every 103.7 ms. The Delay Power Profile (DPP) was computed averaging the squared absolute value of the impulse response for every delay.
- *Scattering function estimation:* A 128-point FFT was computed for every delay sample, and the squared absolute value was applied in order to obtain de delay vs. Doppler channel profile.

The measurements collected revealed a typical delay spread ranging from 1.5 to 6 ms, and a Doppler bandwidth from 0.4 to 2 Hz. Short time channel variations are clearly visible through the analysis of the estimated channel impulse response, the delay power profile and the scattering function. In the following figure absolute value of the time variant channel impulse response (left), scattering function (upper-right) and delay power profile (bottom-right) are shown in a gray color scale for three different channel states.



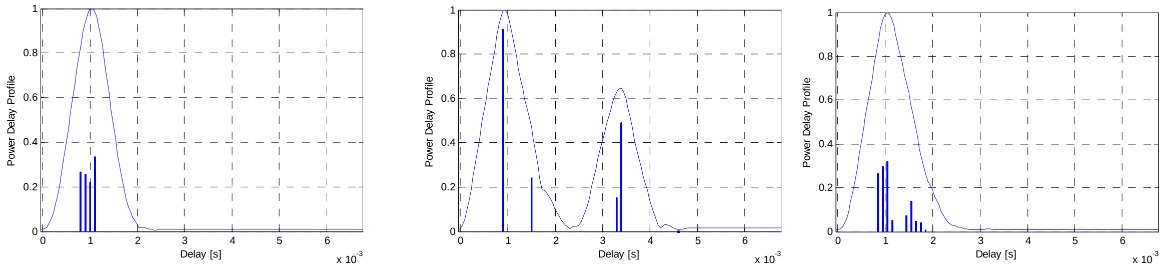
(a) **(b)** **(c)**

Figure 3. (a) Sounding at 8 MHz and 23:16UTC: an example of the lowest delay spread measured. (b) Sounding at 8 MHz and 02:16UTC: two hops are drawn in the time vs. delay modality (b-left). (c) Sounding at 10 MHz and 3:20UTC: another example of high delay spread and high Doppler spread measurements.

4.- Simulation results

An attempt to interpret the structure of the delay power profiles showed in figure 3 take us to consider different ray paths to achieve the target. Due to the high isotropy of the monopole it seems not possible to decide the right elevations and azimuths that allow the link. A proper model to identify the different measured paths of the channel impulse response is required. As a first trial for this purpose we have run the PropLab® software. The input parameters for this software are: the URSI ionospheric model, the Appletton-Hartree ray tracing model with a magnetic dipole field including two exponential collisions terms and the Adams-Moulton integration method [5]. The only experimental data to introduce is the sun spot number (SSN). In order to filter the enormous amount of results that the program produces an own code has been necessary. We can compare our simulation results with the experimental ones.

In figure 4-a (corresponding to experimental figure 3-a) we observe that the simulation affords a unique path. This path starts from the transmitter around 3º of elevation and 46.4º of azimuth. This is a good result but it does not explain why the experimental delay is so spread. In figure 4-b we can



(a) **(b)** **(c)**

Figure 4. Simulated DPP, corresponding to Figure 3 experimental frequencies and times. Simulated ray paths and equivalent measured DPP are depicted, taking into account the sequence autocorrelation and filtering.

clearly distinguish two different paths. The first one is due to an elevation of 6º and 46.5º of azimuth and the second one is around elevation 18º and azimuth 45.4º. Finally, figure 4-c shows two paths in 1 ms of delay. This result can be observed in figure 3-c but the model cannot explain why a high delay spread appears, i.e. the model does not provide another possible path.

The evolution of elevations and azimuths along the time should permit to inform about the layer structure of the ionosphere. Although PropLab® shows good results the computation time for an ionospheric detailed study is too high and the model used by the program is too much theoretical and generalist. Now we are working on a specific model for our link based on the ionosounders that can be found along the path between Livingston Island and Observatori de l'Ebre.

5.- Conclusions and future work

In this paper some results of Antarctica to Spain ionospheric link have been presented. The first version of the sounder was installed, and preliminary information about the channel was obtained. Experimental results show that delay spread ranges from 1.5 to 6 ms, and doppler spread ranges from 0.4 to 2 Hz, depending on the frequency and hour. Although the comparison of simulation results using PropLab® software and experimental results exhibits good correlation in some cases, an specific model for our link would be of great interest. Furthermore the installation of a new FPGA-based sounder in the Antarctic Base is needed to increase the measured bandwidth. The hardware implementation is completed and it is currently being tested in the laboratory. As far the new radiomodem is concerned, a bandwidth up to 30 KHz is being considered, and multicarrier techniques are being developed in order to cope with frequency selective fading and narrowband interferences.

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References

[1] Socoró J.C., Moran J.A., Pijoan J.L., Tarres F., A blind joint channel and data estimation algorithm for DS-SS ionospheric radiolink, International Conference on Achoustics, Speech and Signal Processing (ICASSP'2001), Salt Lake City, USA, 2001.

[2] Cannon P.S, Angling M.J., Davies N.C., Wilink T., Jodalen V., Jacobson B., Lundborg B., Broms M., "Damson HF channel characterisation-a review", *Proceedings of MILCOM 2000*, vol. 1, pp. 59-64, October 2000.

[3] Darnell M., Clark P.D.J., Grob S., "Design and performance of a system for the derivation and analysis of HF channel state data", Eighth International Conference on HF Radio Systems and Techniques 2000, pp. 239-242, July 2000.

[4] Davies N.C., Willink T., Angling M.J., Cannon P.S., "Initial Results from WHISPER; a Wideband HF Ionospheric Sounder for Propagation Environment Research", *Proceedings of Nordic HF conference 2004*, August 2004.

[5] K. Davies, Ionospheric Radio, Peter Peregrinus (1990)