WORKING GROUP 9 PROPAGATION

Report on a completed

Short-Term Scientific Mission (STSM)

funded by EurAAP

Near Vertical Incidence Skywave propagation measurements duplicated in Spain and The Netherlands

Sending Institution:	University of Twente, Enschede, The Netherlands
Hosting Institution:	La Salle Ramon Llull University of Barcelona, Spain
Period:	4 - 17 February 2016
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1. Scope of the STSM

The ionosphere – under influence of the earth magnetic field – splits linearly polarized waves into two circularly polarized waves with opposite rotation sense [1]: magneto-ionic propagation. Our previous empirical NVIS research [2-4] has shown that that two orthogonal (physical) propagation channels can be created using dual circular polarization antennas, potentially doubling channel capacity. All previous measurements where performed on a 110 km long North-South path in The Netherlands (53ºN).

To prove that the concept is not limited to specific azimuth angles and distances, the following experiment was designed: Multiple (4-8) beacon transmitters are set-up at random azimuth angles and random distances between 50 and 200 km around a single receiver site, the transmitters operating at a frequency around 7 MHz. Each beacon switches between Right Hand Circular Polarization (RHCP), Left hand Circular Polarization (LHCP) and linear polarization every 12 seconds. The signal of all beacons is recorded using a high-end digital receiver with 2 coherent antenna inputs, connected to two orthogonal dipoles. From this raw data, simultaneous reception of RHCP, LHCP and linear polarizations can be created. Isolation between the LHCP and RHCP channels will be calculated for each instant in time. The experiment is considered successful when more than 20 dB isolation is achieved. Possible improvement with adaptive elliptical polarization will be studied. Also the fading on the RHCP, LHCP and linearly polarized signals will be characterized and compared.

The vertical angle of the earth's magnetic field – which depends on the latitude of the location – is of influence on the magneto-ionic propagation. To prove that the experiment latitude is not critical to our earlier results, the experiment is first performed in The Netherlands (53ºN), then duplicated in Spain (41ºN), with the assistance of experts of the La Salle Ramon Llull University of Barcelona. Travel and lodging costs for this cooperation are sponsored by the European Association on Antennas and Propagation (EurAAP) through their Short-Term Scientific Mission (STSM) program, which stimulates cooperation between propagation experts of different European countries.

2. Participating Institutions

Research into Near Vertical Incidence Skywave (NVIS) propagation in the Netherlands has been ongoing since 2001 [5] by a small research group led by Ben Witvliet of the University of Twente. The NVIS propagation mechanism is suitable for disaster relief communication, defence communications, tele-medicine and tele-education. The focus of our research at the University of Twente, The Netherlands, is on the interaction between the antenna properties and the propagation mechanism.

In November 2014 cooperation was started with Rosa Maria Alsina-Pagès of the La Salle Ramon Llull University of Barcelona. This university has extensive experience with long-haul ionospheric propagation channels [6-7], and started more recently with NVIS research [8]. Their focus is on modulation, coding and channel modelling, and their research can be considered supplementary to the NVIS research performed by the University of Twente.

The experiment design and the engineering of the required equipment was done by the University of Twente (the visiting institution), and sponsored by the research group of that university, the Telecommunication Engineering group. The equipment was field tested in The Netherlands to assure reliable performance of the equipment.

In parallel to this, La Salle Ramon Llull University of Barcelona (the hosting institution) acquired locations in Spain where the beacon transmitters could be installed and a rural location with very low ambient noise level where the receiver could be installed and made arrangements to allow spectrum use in Spain. Location selection and measurements to identify a quiet rural receive site where done in close cooperation. University of Twente arranged transportation of the equipment (antennas, antenna masts, beacons transmitters, receiver and batteries) to Spain by car and supplied 2 NVIS experts and 1 engineer. La Salle Ramon Llull University of Barcelona provided a second van and 6 staff members to assist with beacon installation. Transportation of equipment and experts from The Netherlands to Spain and lodging were sponsored by the EurAAP through their STSM program.

The preparations of the STSM project took the larger part of 2015, during which frequent interaction via email and Skype took place, and two scientific papers (one in relation to the STSM, and one giving an overview on NVIS communication) where written using online drafting. During the STSM visit to Spain, details concerning the experiment, data analysis and future cooperation where discussed, and a guest colloquium was given. Installation, measurements and recollection of the equipment required intensive labour and long days in mixed Dutch-Spanish teams. The duration of the STSM project - without preparation time - was 2 weeks. Total distance travelled to transport the equipment to Spain and to install and recollect the beacon transmitters in Spain exceeds 6000 km.

3. STSM execution and results

The following chapter describes the execution and the first results from the STSM sponsored cooperation between propagation experts of the University of Twente, The Netherlands and the La Salle Ramon Llull University of Baccelona. Focus will be on the equipment innovation, proof of performance and some initial results of the experiment. This Short-Term Scientific Mission to Spain resulted in a publication [9] on the European Conference on Antennas and Propagation (EuCAP 2016). The full analysis of all measurement data acquired in The Netherlands and Spain is ongoing, the outcome of which will be reported in a scientific article.

3.1 Design of a transportable hybrid antenna-transmitter system for NVIS propagation research

In our previous propagation measurements a 200 Watts NVIS transmitter and a Turnstile antenna [10, pp. 726-729] were used, installed at a fixed location and fed from the electrical power grid. Duplicating such an installation for 8 locations in The Netherlands and 6 locations in Spain would be expensive and installation and operation would be impractical. Therefore the experiment required an innovative design for the beacon transmitters. The design of this new hybrid antenna-transmitter system [9] is published on the scientific conference EuCAP2016, which is organized by the EurAAP.

Acquisition of a new dual channel measurement receiver and reduction of the receiver bandwidth, made a transmit power reduction to 2 Watts possible, and the entire system is now fed by a single 13.5 Volt battery at the foot of the antenna mast. This allows installation in locations where no electrical power connection is available, locations best suited for the intended polarization measurements. Mounting the now much smaller transmitter at the antenna feed point eliminates the antenna feed lines that would otherwise have to be calibrated for identical length and buried underground to avoid interaction with the antenna. The completed system is shown in Figure 1. The previously used analog phasing lines to generate circular polarization are now replaced by the use of 2 synchronous digital transmitters connected to the feed point of 2 perpendicular dipoles, as shown in the block diagram of Figure 2. By programming 90 degrees phase difference between these transmitters, circular polarization is achieved. The mast consists of tubular telescoping sections, and the complete beacon is easily transported. The total weight of the set-up is 30 kg, half of which is in the battery. In moderate weather, the beacon can be set-up by a single person in 1.5 hours, or by 3 persons in 40 minutes.

Figure 1: (left) The beacon transmitter is mounted at the feed point of the wire dipoles, and is fed from a 13.5 Volt battery located at the foot of the mast. (right) The entire system is easily transported and can be set-up by a single person in 1.5 hours.

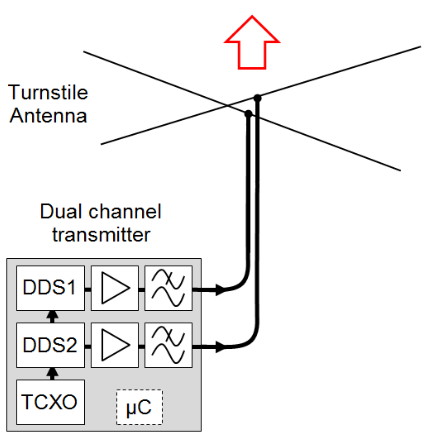

Figure 2: Block diagram of the hybrid antenna-transmitter beacon system to produce precisely controlled circular or elliptical polarization for NVIS propagation research.

3.2 Transport to and installation in Spain

To transport the equipment from the Netherlands to Spain, a rental van is used. Figure 3 shows the van stocked with 8 hybrid antenna-transmitter beacons, a receiver system, spare parts and tools, just prior to departure on the Short-Term Scientific Mission. Only 6 beacon sites where planned in Spain, the 2 other systems served as spare.

In Spain the equipment is divided over two vans, manned by two mixed Dutch-Spanish teams, for the installation of the beacons in a circle with a radius of 50 to 100 km around the receiver site. The beacon locations range from suburban to remote and mountainous. The line-of-sight path from beacon transmitters to measurement receiver is blocked by multiple mountain ridges, making the NVIS propagation experiment an excellent demonstrator for ad-hoc radio communication without the use of any intermediate infrastructure. The beacon and receiver locations can be found in the map in Figure 4, pictures of the beacon and receiver installation can be found in Figures 5-7.

Figure 3: Eight hybrid antenna-transmitter beacons, a receiver system, spare parts and tools stocked in the van just prior to the Short-Term Scientific Mission.

Figure 4: Map showing the 6 beacon locations and the central receiver location in North-East Spain.

Fig 5 Beacon 1 in Rivert (left) and beacon 2 in Cal Cerdanyola (right).

Fig 6 Beacon 3 in La Masia (left) and beacon 4 in Castellet (right).

Fig 7 Beacon 5 in Mas Anguera (left) and beacon 6 in Menarguens (right).

3.3 First observations and results

The beacons transmitters were programmed to transmit from 08:00-18:00 local time, to cover the daytime NVIS propagation interval on 7 MHz. Propagation was very poor during the weeks prior to the planned measurements, promising 3 hours of constant propagation and 2 hours of intermittent propagation only. Vertical sounding ionospheric measurement data was used from the ionosonde of the Ebre Observatory, which is located approximately 120 km South-West of the measurement receiver site. As propagation changed from very poor to excellent on the day of the measurements, the beacon transmitters could be observed during the entire 10 hour entire interval. Despite the low power (2 Watts output), the signal-to-noise ratio at the receiver exceeded 50 dB in a 10 Hz bandwidth during a large part of the day, while 20 dB would be sufficient for accurate measurements. University staff living within the city of Barcelona (where man-made noise levels are high) reported the beacon transmitters 30 dB above the noise level on a simple wire laying in the attic of the house.

The measurement receiver system consist of a coherent dual channel digital receiver with high (>>100 dB) intermod free dynamic range, connected to two perpendicular dipoles. By observing the amplitude and phase difference between coherently obtained samples of both antennas, the polarization and the total signal strength can be determined on a per-sample basis. During the entire measurement interval the raw data samples from both perpendicular antennas are recorded at a measurement speed of 6000 samples/second. The raw data can be post-processed to produce two data streams of RHCP and LHCP polarization, or any other desired polarization.

To verify the presence and signal-to-noise ratio (SNR) of the beacon transmitters, the raw data of each channel can be converted to a spectrogram using the Fast Fourier Transform. Figure 8 shows the spectrogram of a fragment of the data recorded around 08:30 local time. This is shortly after the NVIS propagation path opened, yet the SNR already exceeds 40 dB. The received signal amplitude of the 6 beacon transmitters can be seen, as well as their preprogrammed transmitting pattern. Transmission is in the 7 MHz amateur radio band, beacon identification is in Morse code.

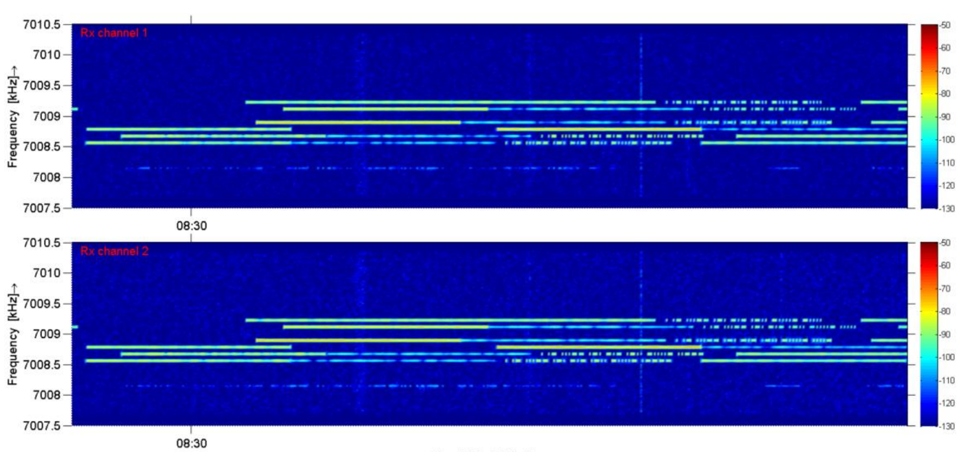

Figure 8: A dual spectrogram of a short fragment of the recorded data of the dual channel receiver. Here the signal of the 6 beacon transmitters is >40 dB above the ambient noise level, each at its own frequency (110 Hz separation). Beacon identification is in Morse code.

Each transmitter follows a transmit sequence that repeats every full minute, divided in five 12 second slots, as shown in Figure 9. First slot is LHCP, second RHCP, third slot contains identification in Morse code, fouth slot is linear polarization and during the fifth slot the transmitter is off. The starting moment when the beacon switches on in the morning is not precise, but the timing of the 12 second interval is derived from the 2.5 ppm Temperature Compensated X-tal Oscillator (TCXO) seconds and therefore very precise. The 'silent' interval is included to allow easy synchronization of the data analysis with the transmit sequence.

During the morning 'Happy Hour' propagation interval [4] only the extraordinary wave is propagating, and only the waves transmitted upwards in LHCP are reflected to arrive as RHCP waves at the receiver. This can be clearly seen when we zoom in on the signal of one of the beacons, recorded around 08:30 local time: the first slot is received >20 dB stronger than the second slot. This is observed on each of the beacons. Timing of the 'Happy Hour' is slightly different for each beacon, which corresponds with theory and is due to the location differences of the beacons. Once the 'Happy Hour' interval is over, both polarizations arrive with the same signal strength. This preliminary result already confirms the main goal of the experiment is achieved. Full data analysis and comparison of the results obtained in Spain with earlier measurements in The Netherlands is ongoing and will be subject to a scientific article linking these results with earlier findings.

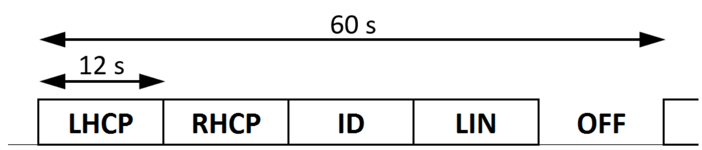

Figure 9: Pre-programmed transmit sequence of the beacons. The 'off' interval is inserted for synchronization of the analysis software with the transmit sequence.

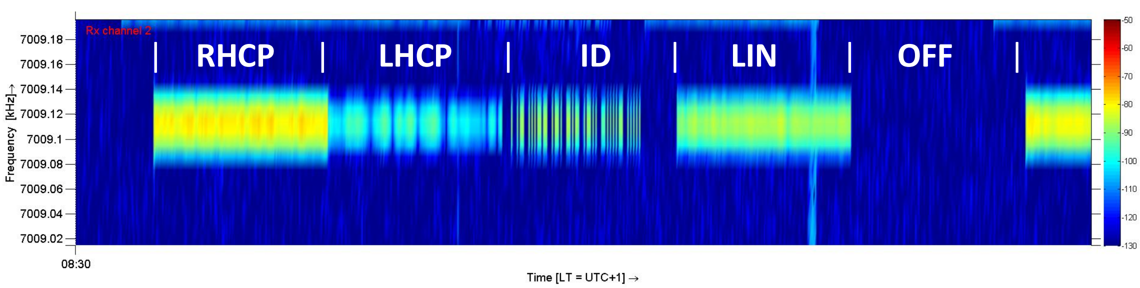

Figure 10: During the morning 'Happy Hour' propagation interval [4], only the extraordinary wave is propagating. This can be clearly seen if we zoom in on one of the beacons from 08:30:00-08:31:10 local time: the first slot (RHCP) of the sequence is received >20 dB stronger than the second slot (LHCP). Note: an upward LHCP wave results in RHCP downward wave.

4. Conclusions

The EurAAP Short-Term Scientific Mission (STSM) program enabled this cooperation between propagation experts of University of Twente, the Netherlands, and La Salle Ramon Llull University of Barcelona, Spain, both in practical work in the field and in theoretical discussions at the university. EurAAP sponsored travel and lodging during the experiments. The duplicate NVIS propagation and polarization measurements in Spain would not have been possible without this sponsoring. Additionally, the quest for transportable and easily installed beacon transmitters led to the design of a novel antenna-transmitter hybrid, which performed very well in the field. The design is published on the EuCAP 2016 conference.

The STSM was successful: all beacons could be installed and worked as planned, the ambient noise level at the selected receive site was very low and ionospheric propagation was better than expected. All beacons could be received with high SNR values (>50 dB), a prerequisite for accurate measurements. A first brief analysis of the Spanish data seems very promising: approximately 20 dB isolation between RHCP and LHCP was demonstrated during ‘Happy Hour’ propagation. Full data analysis and comparison of the results obtained in Spain with earlier measurements in The Netherlands is ongoing and will be subject to a scientific article linking these results with earlier findings.

5. Acknowledgment

The author thanks Rosa Ma Alsina Pagès of La Salle Ramon Llull University of Barcelona for the excellent cooperation throughout 2015, based entirely on email and Skype communication, resulting in this well-prepared Short-term Scientific Mission and 2 scientific publications. And also for the organisation and hard work in the field during the STSM itself. Her contribution was essential for the success of this STSM.

We thank Enric Fraile i Algeciras, head of the La Salle Radio Club, for the kind use of the amateur radio license of the Radio Club for the operation of the beacon transmitters. We thank David Badia Folguera for the selection of the quiet rural receiver location and the radio noise measurements at the location in the planning phase, David Altadill of the Ebre Observatory for the scaled ionospheric data and Marcos Antonio Hervas Garcia for the discussions on data analysis at the university and in the field.

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He worked in electronic maintenance in Israel, helped setting up the International (telecommunication) Network Management Center (INMC) in The Netherlands, worked as Chief Engineer of the high power (2x 300 kW) shortwave radio station of Radio Netherlands World Service in Madagascar and managed a team of technical specialists for TV, FM and AM broadcast transmitter operator NOZEMA in The Netherlands. Since 1997 he works for Radiocommunications Agency Netherlands, Groningen, The Netherlands, currently as Technical Advisor. Since 2011 he combines his work with research in the Telecommunication Engineering group of the University of Twente, The Netherlands. Previous research includes UHF trans-horizon propagation measurements, helicopter-based antenna diagram and EIRP measurements of broadcast stations and radio noise measurements. Current research interests are Near Vertical Incidence Skywave propagation and its application to emergency communications, radio noise, and dynamic spectrum management.

Dr. Witvliet is a Senior Member of the IEEE since 2011 and a member of EurAAP since 2014. He has represented The Netherlands in ITU Study Group 3 (Propagation), European Communication Committee (Spectrum Management) and the European Telecommunication Standards Institute. He has won Best Poster Awards from URSI Benelux and the National Antenna Research Framework in 2014, and was awarded the Veder Price in 2015.

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