Thoughts on NVIS circular polarization by PA3ECT

Following the research and the publications of Jan Simons PAoSIM and of the group around Ben Witvliet PE5B on circular polarization in NVIS propagation, a lot of questions concerning this phenomenon remain. I'm not a scientist, so I discussed my thoughts and questions with Ben Witvliet PE5B.

These are the publications

1a "The Importance of Circular Polarization for Diversity Reception and MIMO in NVIS Propagation", European Conference on Antennas and Propagation, The Hague, The Netherlands, April 2014.

1b same, poster.

2 "Near Vertical Incidence Skywave (NVIS) Antenna and Propagation Research in The Netherlands" [poster], URSI Benelux Forum, Louvain-la-Neuve, Belgium, November 2014.

3 "Near Vertical Incidence Skywave Propagation: Elevation Angles and Optimum Antenna Height for Horizontal Dipole Antennas". IEEE Antennas and Propagation Magazine, February 2015.

4a "Characteristic Wave Diversity in Near Vertical Incidence Skywave Propagation", European Conference on Antennas and Propagation, Lissabon, Portugal, April 2015.

4b same, presentation.

5 "Measuring the Isolation of the Circularly Polarized Characteristic Waves in NVIS Propagation", IEEE Antennas and Propagation Magazine, June 2015.

The publications can be found via the weblinks in the upper right menu (marked with **), on the ResearchGate website of B. A. Witvliet and on the website van AT.

These are the authors

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First a few definitions

Near Vertical Incidence Skywave (NVIS): reflection in the ionosphere under steep angles.

Circular polarization (CP): an electromagnetic wave of which the polarization shows rapid (left or right hand) rotation during its propagation: one full rotation for every wavelength of traveled distance.

Left Hand Circular Polarization (LHCP): counterclockwise rotation, seen in the direction of travel (IEEE definition).
Right Hand Circular Polarization (RHCP): clockwise rotation, seen in the direction of travel.

Characteristic wave: the radio waves that propagate in the ionosphere: the "ordinary wave" and the "extraordinary wave".

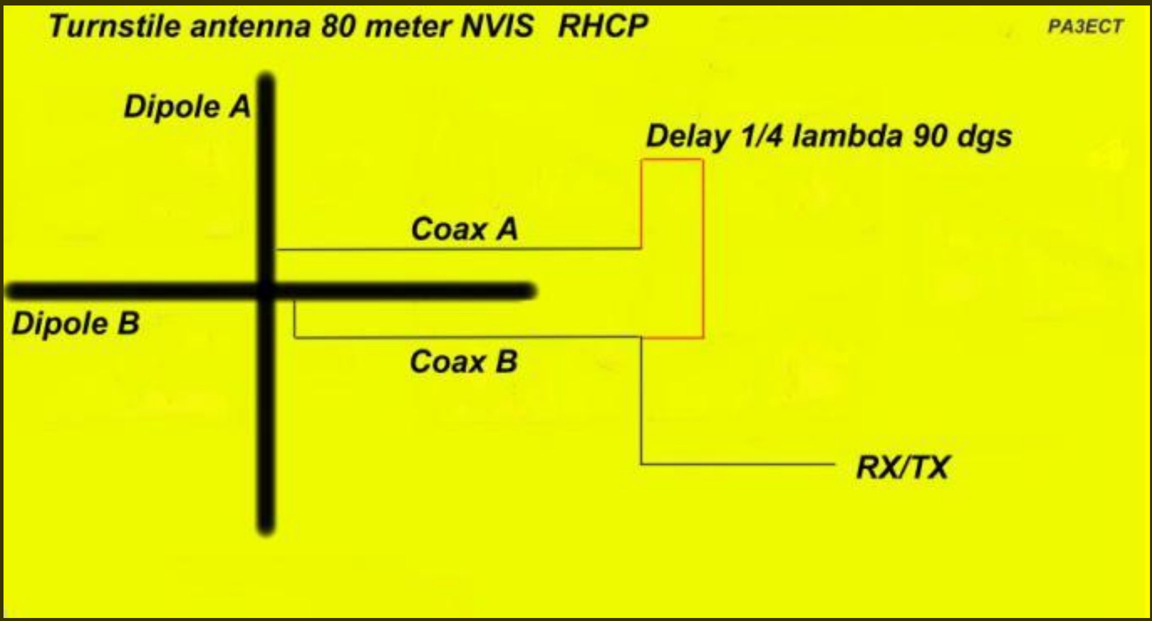
Ordinary wave: upward travel RHCP, downward travel LHCP. Red traces in graphs and ionograms.
Extraordinary wave: upward travel LHCP, downward travel RHCP. Green traces in graphs and ionograms.

Happy Hour: the time interval in which, on a certain frequency, only the extraordinary wave is reflected. The received wave is circularly polarized, even if the transmit antenna has linear polarization. A Happy Hour exists in the morning, when propagation just starts, and in the evening, when propagation ends.

Turnstile antenna: an antenna that consists of two perpendicular half-wave dipoles that are fed with 90 degrees phase difference. In the direction perpendicular to the plane of the dipoles the polarization is circular.

How does a Turnstile antenna work?

In the figure below dipole A en dipole B are two half-wave dipole antennas that are suspended at the same height above ground and perpendicular to each other. Both dipoles are fed with coaxial lines of equal length, coax A and coax B.
De delay line creates a 90° phase shift, its length is a quarter wavelength multiply by the velocity factor of the cable. At the point where both coax B and the delay line join, the impedance must be adapted to the impedance of the feed line to the receiver or transmitter.



<u>What happens on an incoming RHCP wave?</u>

The figure provides a top view of the antenna. When a RHCP wave descends on the antenna, the polarization will match the polarization of dipole A at a certain instant in time. A quarter period later – which corresponds to a 90° right hand rotation - the polarization matches that of dipole B. As the feed line of dipole A has been extended with a 90° delay line, both signals will still arrive at the same time (in phase) at the connection point and add. The combined signal travels to the receiver (RX).

<u>What happens on an incoming LHCP wave?</u>

When a RHCP wave descends on the antenna, the polarization will match the polarization of dipole A at a certain instant in time. A quarter period later – which corresponds to a 90° left hand rotation - the polarization matches that of dipole B, but now with reversed polarity. Compared with RHCP there now is 180° additional phase shift. Both signals now meet each other in anti-phase at the connection point and cancel each other. The remaining signal traveling to the receiver (RX) is now strongly attenuated***.

<u>Switching between RHCP and LHCP</u>

When the delay is transferred from coax A to coax B, the antenna becomes suitable for LHCP. We can also lengthen the delay line from 90° to 270°.

**** Additional information of Ben Witvliet PE5B:*

To achieve 20 dB isolation between RHCP en LHCP (cross-polarization), the phasing network has to be quite good: the power difference between the dipole antennas should not be greater than 0.5 dB en the phase error should not exceed 5°. To achieve that, a good quality power splitter must be used and both antennas, baluns, etc. must be as identical as possible. The attenuation of the delay lines and the electrical length of the relays must be compensated for. How to achieve even 25 dB cross-polarization, with switchable polarization, can be read in publication 5.

Thoughts and/or questions of PA3ECT

1. <u>No multipath fading during Happy Hour?</u>
In the Happy Hour there will be no interference due to the two signal paths with RHCP and LHCP.

Reply Ben Witvliet PE5B:
It is better to talk about the two signal paths of de ordinary wave and the extraordinary wave, as the polarization of the extraordinary wave is upwards LHCP en downward RHCP. It is correct that in the Happy Hour there is no interference between the ordinary and extraordinary wave, so there is no polarization fading (fading in which both the signals strength and polarization vary rapidly). Even though there is no polarization fading during Happy Hour, there may still be multipath fading due to multiple path between transmitter and receiver for the extraordinary wave.

2. <u>Antenna gain by polarization matching?</u>
With Turnstile antennas a gain of 3 dB per antenna can be achieved.

Reply Ben Witvliet PE5B:
That is only true during Happy Hour, and is actually no gain, but 3 dB reduction in loss.
By transmitting only with LHCP during Happy Hour, no power is lost in the ordinary wave, which will not arrive at the receiver anyway. By receiving RHCP only, all the power of the incoming wave is captured, while a linearly polarized antenna would only receive half the power. Outside Happy Hour there is no power gain, but clever application of CP may be used for fading reduction, see publication 4. The antenna gain of a Turnstile antenna is identical to that of a single dipole above ground.

3. <u>Reversal of polarization between transmission and reception?</u>
When a station transmits with LHCP the reflected wave will be RHCP and vice versa. The mirror in the ionosphere also reverses the rotation. Consequently the stations would need to switch antenna polarization when switching from transmission to reception.

Reply Ben Witvliet PE5B:
To picture the ionosphere as a mirror is a simplification that is not correct for characteristic waves. But there is indeed a reversal from LHCP upwards, to RHCP downwards for the extraordinary wave, and from RHCP upwards to LHCP downwards for the ordinary wave.

4. <u>What if only one of the stations uses circular polarization?</u>
When a station with a Turnstile antenna contacts a station that uses a dipole antenna, this is of no concern to the station with the dipole antenna, but the station with the Turnstile antenna has to switch polarization between transmission and reception.

Reply Ben Witvliet PE5B:
Even when the station with the Turnstile antenna doesn´t switch, both stations will hear each other for the greater part of the day, as both the ordinary and the extraordinary wave propagate. If he chooses to switch he can choose the propagation mode (ordinary or extraordinary wave) that will provide the least fading or the greatest signal strength. Which depends on the momentary propagation and the frequency band used. Only during Happy Hour – when only the extraordinary wave propagates – the CP station must transmit with LHCP and receive with RHCP. If not, there will be one way propagation.

5. <u>Conversion of an wave into an extraordinary wave?</u>
Outside the Happy Hour, when a Turnstile antenna is used to transmit with RHCP, a LHCP wave is reflected by the ionosphere. Is a RHCP signal created in the ionosphere also, just as with the linearly polarized dipole? Or less? How much less?

Reply Ben Witvliet PE5B:
No, our measurements show that the isolation between LHCP en RHCP is at least 25 dB. Our measurement system could not measure more than 25 dB isolation, but the measured transition curves indicate that the actual isolation probably is much higher still, possibly >32 dB.

Additional information from Ben Witvliet PE5B:

With a linearly polarized dipole antenna the ordinary wave and extraordinary wave are not created at the reflection, but as soon as the upward wave enter the ionosphere, already at approx. 80 km height. Linearly polarized wave do not propagate in the ionosphere, but circularly polarized waves do. Two circularly polarized waves with opposite rotation sense are created, that have the same total power and the same summed polarization as the wave that entered the ionosphere. Each of these two characteristic waves travels its own path through the ionosphere, often with tens of kilometers difference in height. The isolation between the waves is large.

6. <u>Does the ground underneath the antenna degrade circular polarization?</u>
Is it correct that the polarization switching has less effect when the earth reflects well? By this reflection the polarization rotation will be reversed and the signal will be received from under again? Reasoning:

a) For a dipole antenna with linear polarization at a quarter wavelength above ground, the reflection travels a halve wavelength. During this time the signal in the antenna has advanced 180° in phase, so both waves are in phase. When the reflection is ideal, this results in 3 dB gain, as both waves travel upward and are in phase.
b) For a Turnstile antenna the rotation sense has been reversed by the ground reflection. Therefore the reflected wave will never be in phase with the direct wave. Is reversal of the rotation sense already present so close under the antenna?

Reply Ben Witvliet PE5B:
If this were true a VHF crossed-Yagi antenna would not work either, because of the presence of a reflector element behind the dipole. Luckily this reasoning is incorrect and those antennas do work.

a) The pictured interaction of ground and dipole antenna is incorrect. The earth is not a perfect mirror without loss and phase shift. And antenna gain cannot be calculated by summing the direct ray and the reflected ray in one direction. It is necessary to consider the distribution of the power supplied to the antenna in all angular directions, and how much is concentrated in the direction of the main beam. The maximum gain of a dipole antenna above ground is 4 tot 5.5 dBd and the optimum is certainly not at a quarter wavelength height, but lower, see publication 3.
b) A few attempts to explain this:
   - You cannot explain the influence of the ground under the antenna using optics: there is no flat wave front and we are not in the in the far field. The currents in antenna and ground are strongly coupled, similar to the currents in a 2 elements Yagi antenna with radiator and reflector. It is better to consider dipole and ground as one antenna, similar to the Yagi antenna. So we have two perpendicular and identical antennas with very little coupling between them (<-25 dB). The phasing networks causes the radiated linearly polarized fields of both antennas to be 90° shifted in phase. The summed field is circularly polarized.
   - If forcedly regarded as an optical reflection, look at is as follows. One dipole antenna above ground emits a sine wave. The ground reflection returns at the antenna with a distinct phase difference, and as to the wave that is transmitted upward. As the direct wave and the reflected wave are both sine waves, their summation is also a sine wave, but with a different amplitude and a phase shift. As the second dipole is at the same height above ground, its phase shift is exactly the same. So the ground underneath the antenna has no influence on the circular polarization.
   - And also reasoned from optics: when a Turnstile antenna transmit LHCP upwards, it transmits RHCP downwards and the reflection by the ground upwards is again LHCP. Maybe the reasoning concerning reversal of rotation sense by ground reflection was mixed up with such an effect for a circular polarized VHF crossed-Yagi antennas radiating towards the horizon? For NVIS it is by all means incorrect.

Concluding: this reasoning about an unfavorable ground reflection is incorrect.

7. <u>Are RHCP en LHCP present during Happy Hour due to ground reflection?</u>
As the Turnstile antenna transmits RHCP waves and the ground reflection is LHCP, both waves will be present outside the Happy Hour interval. The same is true on reception. So QSB will be generated again. To achieve a separation between the ordinary and extraordinary wave outside the Happy Hour interval there should not be a ground reflection, if both stations use a Turnstile antenna.
Preliminary conclusion would be that the highest isolation between LHCP en RHCP outside Happy Hour can be achieved with Turnstile antennas above a nonreflecting ground.

Reply Ben Witvliet PE5B:

No, our measurements in December 2014 – in which we transmitted alternatingly with RHCP and LHCP – show that during the entire NVIS propagation interval the isolation between RHCP and LHCP is greater than 22 dB, probably even greater than 32 dB. This value would have been unattainable if the ground reflection had a reverse rotation, as the ground reflection is at best a few dB weaker than the direct wave. So this reasoning is incorrect.

8. What is the optimum height of a Turnstile antenna?
If the ground reflection does not have a positive contribution to the NVIS signal, is the optimum height of the Turnstile antenna still the same as that of a linearly polarized dipole antenna?

Reply Ben Witvliet PE5B:
The assumption of a negative influence of the ground reflection is incorrect. The contribution of the ground reflection to the NVIS signal is significant and positive, it produces an antenna gain of 4 to 5.5 dBd, see publication 3. And a cross-polarization of >25 dB is attainable, see publication 5. But yes indeed, the optimum antenna height for a dipole antenna and a Turnstile antenna consisting of two perpendicular dipole antennas is the same.

Additonal information from Ben Witvliet PE5B:
The interesting aspect of science and research is that there is always a new horizon when you think you have already gone a long way. So we certainly do not know everything, and we continue our research, especially doing accurate measurements on NVIS antennas en NVIS propagation. This fall (2015) we hope to perform precision measurements again in The Netherlands and Spain, together with the LaSalle University of Barcelona. We will publish our results, of course!