October 2023 Annular Eclipse Propagation Anomalies at HF: Preview of FST4W Observations

Part 4: Doppler shift - Measuring the rate of change of one-hop path lengths

Gwyn Griffiths G3ZIL gwyn@autonomousanalytics.com

Doppler shift to rate of change of path length

With GPS disciplined master oscillators at each end the difference between a precisely known transmitter frequency (to better that 10 mHz at 10 MHz) and the frequency as calculated by FST4W at the receiver is an estimate of the Doppler shift induced by a changes in the ionosphere. It is straightforward to convert Doppler shift Δf to the rate of change of path length:

$$dP/dt = -\Delta f.c/f \qquad (1)$$

where P is path length, c speed of light and f transmission frequency. That is as far as we go in this note. Subsequent processing to arrive at ionosphere height changes [1] requires assumptions on initial height too detailed for a one-page preview.

Quantization error from 0.1 Hz frequency resolution in FST4W sets the limit for this work at present.

Multi-frequency measurements on a 545 km path

Our example is the path from WO7I (DN10cw, NV, 89% obscured) to ND7M (DM16xf, NV, 87% obscured, KiwiSDR). The transmitter at WO7I was a WB6CXC BB-6 [2] with simultaneous transmissions on 3.570045, 7.040045 and 10.140145 MHz giving useful Doppler data every 2 minutes, Figure 1. Higher frequencies were within the skip zone.

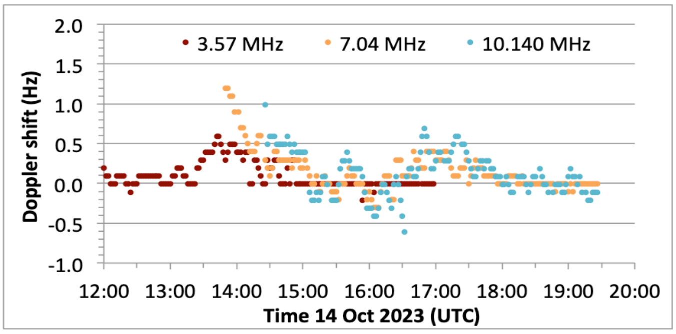

Figure 1. Doppler shift at three frequencies from simultaneous transmissions from WO7I to ND7M. 3.5 MHz was open during the night, 7 MHz, then 10 MHz, opened as the F2 layer critical frequency rose after dawn.

3.5 MHz was open during the night, hence we did see the very start of the descent of the peak in F layer ionisation at ~13:22 UTC (05:34 Local Solar Time) as an increasingly positive Doppler shift. Doppler shift plateaued before reducing to zero, *implying* the ionisation had reached its daytime height as the F2 layer.

The critical frequency was too low for 7 MHz to show the start of the ionisation peak descent. We caught it from 13:50 UTC. 10 MHz opened even later, at 14:26 UTC, even so, the Doppler shift was still positive: the ionisation peak was still descending.

Doppler shifts at 7 MHz and 10 MHz after about 14:12 UTC were in stark contrast with mostly zero Doppler at 3.5 MHz. A working hypothesis is that after 14:40 UTC 3.5 MHz propagation was not F2 but via the E layer. Between 14:12 and 14:40 UTC the path on 3.5 MHz was likely flipping between E and F2; hence interspersed zero and non-zero Doppler shifts. The implication, yet to be checked for feasibility, is that the E layer was not changing height.

Rate of change of path length

Next, we apply eqn. (1) to the Doppler shifts, resulting in the rate of change of path length estimates in Figure 2. It is encouraging that the path velocity estimates from the three frequencies (when

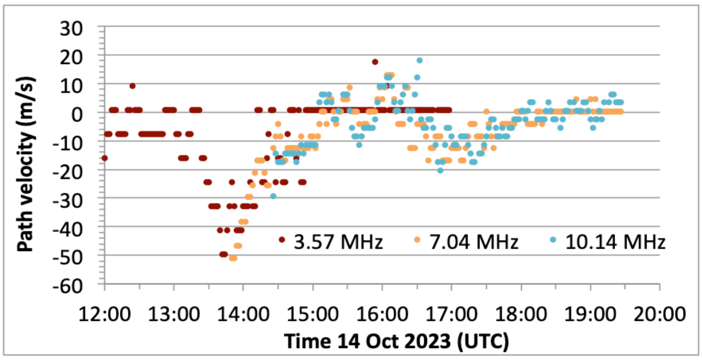

Figure 2. Path velocity, that is, rate of change of path length, derived from the Doppler shift at three frequencies and eqn. (1). The measurements are consistent across the three frequencies until, we hypothesize, the 3.5 MHz refraction was from the E layer after 14:40 UTC

3.5 MHz was via F2) overlie each other. Frequency spread measurements showed all were one-hop.

Rate of change of path length during the eclipse

Focusing in around the time of the eclipse, Figure 3 shows path velocity averaged over 10 minutes every 5 minutes. The maximum positive path velocity at both 7.04 and 10.14 MHz was at 16:05 UTC at 10.3 m/s and 10.4 m/s respectively - essentially the same. That is, both frequencies showed a lengthening path - the height of maximum ionisation was rising. This was 19 minutes *before* the maximum eclipse at 16:24 UTC at the path mid-point (38.56°N 116.9°W, deep partial at 91%). While the two frequencies showed very similar path velocities at and before 16:05 UTC from then until 16:50 UTC the 10 MHz values were more positive. Perhaps this was due to different refracting heights for the two frequencies within a dynamic F2 region.

This is a fascinating data set and the variations need to be compared with days prior to and after the eclipse. Also, ionosphere height changes will be determined.

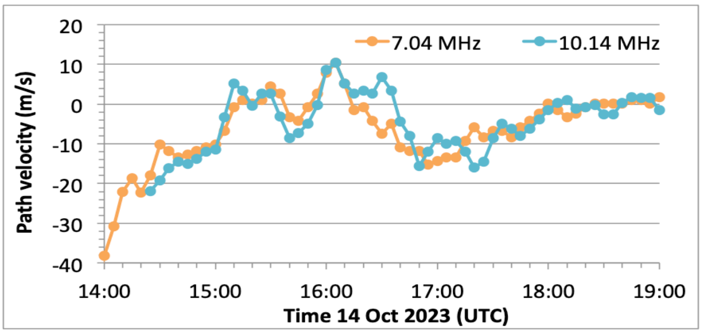

Figure 3. Path velocity around the time of the eclipse: 16:24 UTC at the path mid point.

Data availability

All data is open access. A Guide is available [3], with an Annex on access methods. Sites wspr.rocks and wspr.live also provide access and graphical outputs. Please acknowledge Rob Robinett AI6VN and individual data contributors in any output as below.

References

1. Collins, K. et al., 2022. Methods for Estimation of Ionospheric Layer.... *EGUsphere*, *2022*, pp.1-24.

2. https://turnislandsystems.com/

3. http://wsprdaemon.org - see guide on the Timescale page.

Acknowledgment

Data acquisition for this preview was only possible through the efforts of Rob Robinett AI6VN, Paul Elliot WB6CXC, Tom Bunch WO7I and Dennis Benischek ND7M. V1. 31 Oct 2023