WWV Time Tick Arrival Time Study to Investigate Multiple Modes During Daily Dawn and Dusk Transitions

Ft. Collins, CO to San Antonio, TX Path

40.68 -105.04 to 29.57 -98.89

On January 29, 2020

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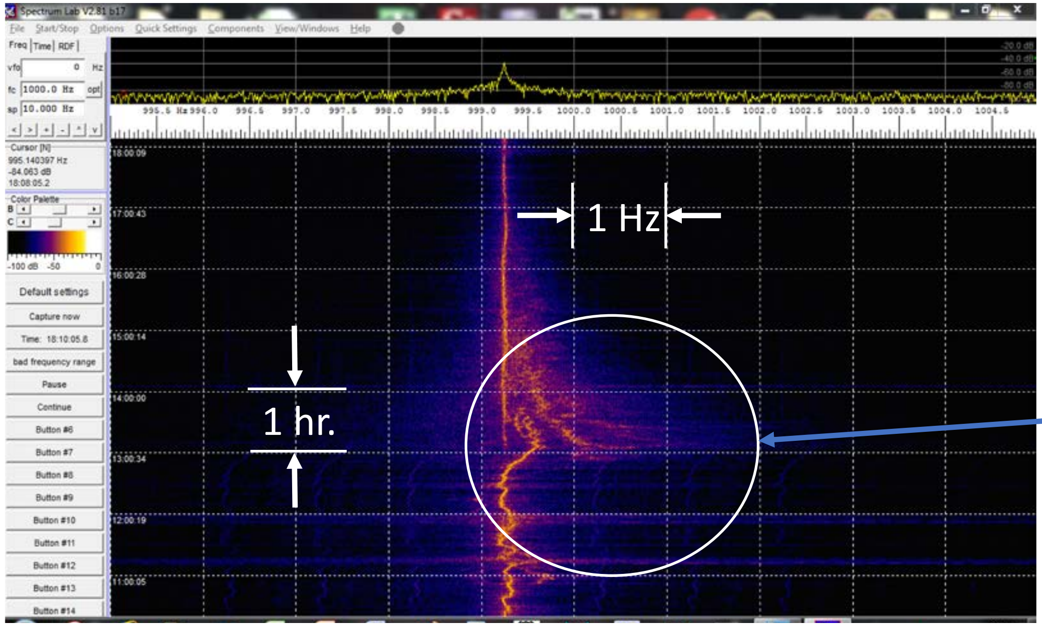
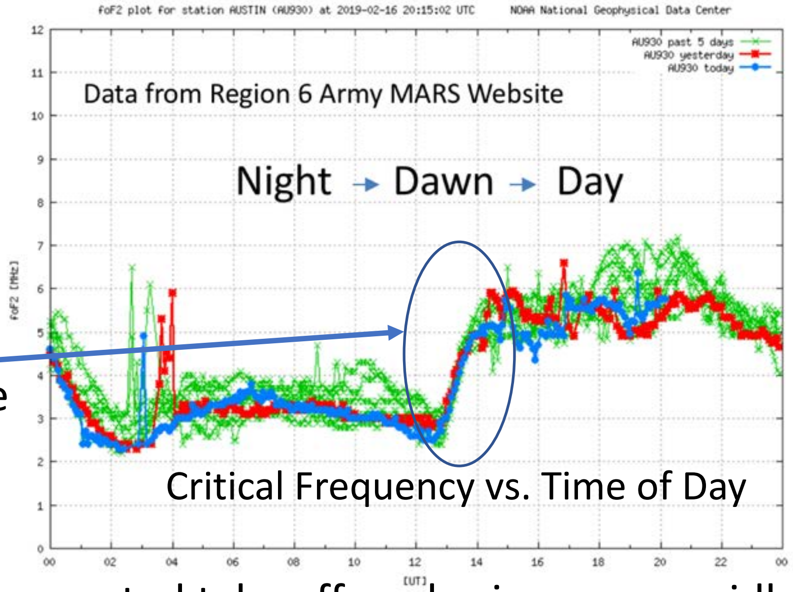
March 20, 2020

Timing Study Motivation: Learn More About Multiple Frequency Tracks During Dawn and Dusk “Amok Time” by Investigating Tick Arrival Times

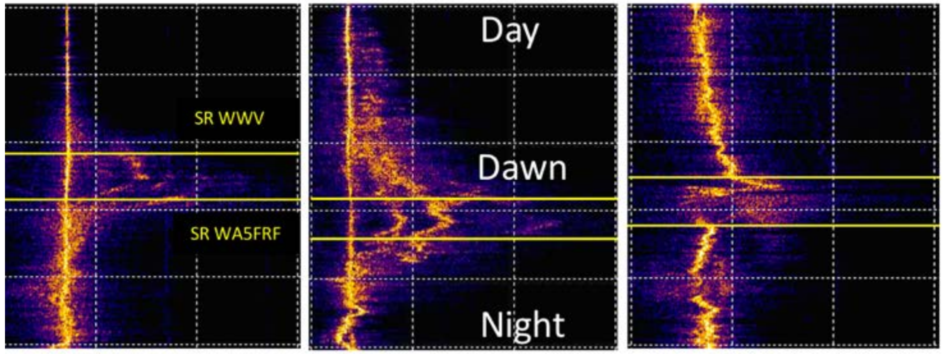


Amok Time



1. Multiple frequency modes during the dawn transition were observed on 2.5 and 5 but not 10 MHz WWV.
2. The modes usually occur in a geometric frequency progression suggesting multiple propagation paths with increasing rates pf path closure. The opening of simultaneous multiple hop modes could explain the periodic Doppler tracks.
3. The Critical Frequency slewed through 5 MHz at dawn but never reached 10 MHz, possibly explaining absence of multiple modes on 10 MHz and reaffirming requirement for high angle propagation.
4. The requirement for high angle propagation is reinforced by the sudden appearance of overtone modes midway through the transition: the mode did not manifest until propagation at the required angle was supported.

Supported take off angles increase rapidly



2.5 MHz 02/17/2019 | 5.0 MHz 10/14/2018 | 10 MHz 10/30/2018

Time of Flight Analyses Can Help Identify the Path Taken by Primary and Delayed Copies of WWV Timing Ticks and Help Doppler Analysis

FREQUENCY DOMAIN

Multiple hop modes appear when high angle propagation is supported. An hypothesis is that Doppler scales with number of hops because the longer path lengths experience a faster rate of distance closure with descending reflection height.

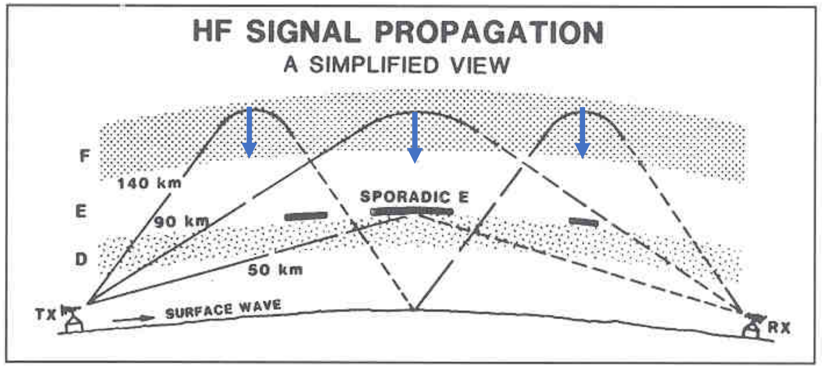
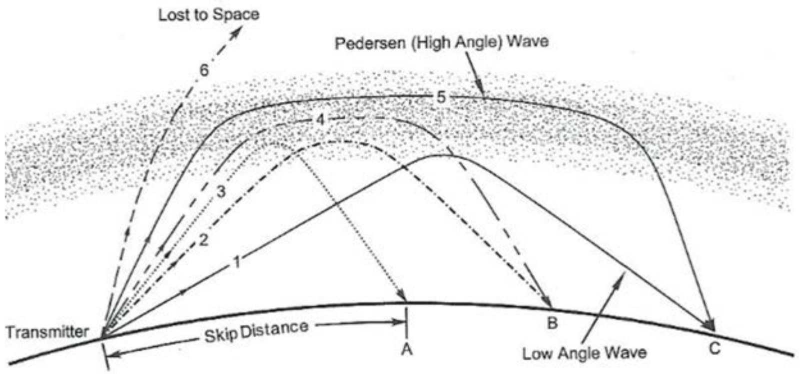


Figure 1. Radio wave propagation using the ionosphere. Courtesy Gerald Oicles/BR Communications, Sunnyvale, CA

TIME DOMAIN

Multiple hop modes have a longer path length that can be deduced by Time-Of-Flight measurements. Information on reflection height descent rate, and therefore Doppler, can be inferred from rate of path closure.

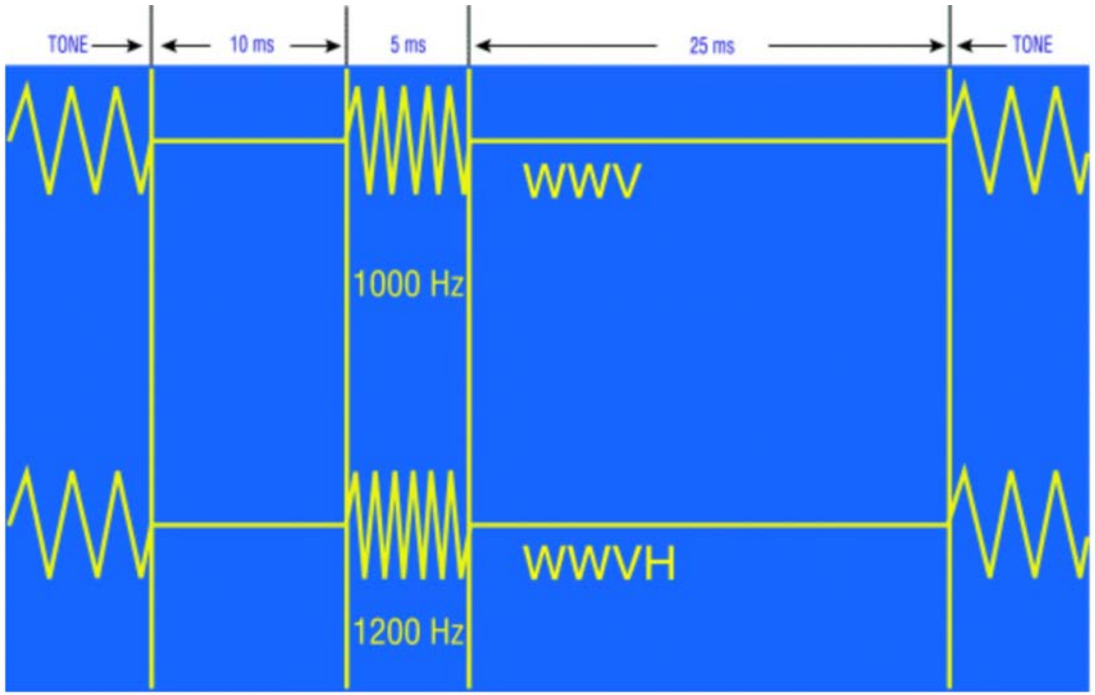
Addition complications at dawn include appearance of Pedersen waves, strengthening of the D and E layers, splitting of the F layer, refraction at multiple heights, accelerating wave velocities and simultaneous presence of WWV and WWVH carriers, each with their own Doppler shifts. Insights into this complex process can be gained from timing analyses.



From ARRL Antenna Book

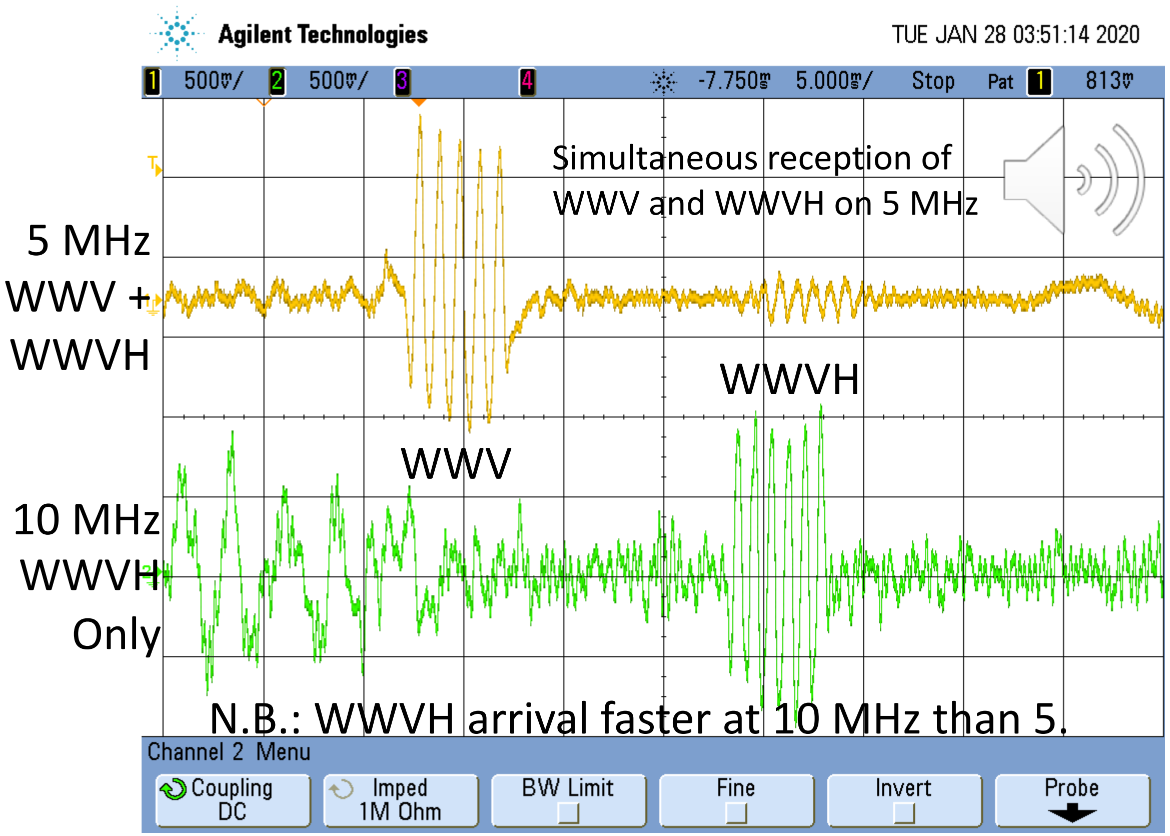
A Pedersen Wave is a high angle, extended path, single hop mode that spends more time in the ionization region.

WWV and WWVH 1-pps Timing Tick Format



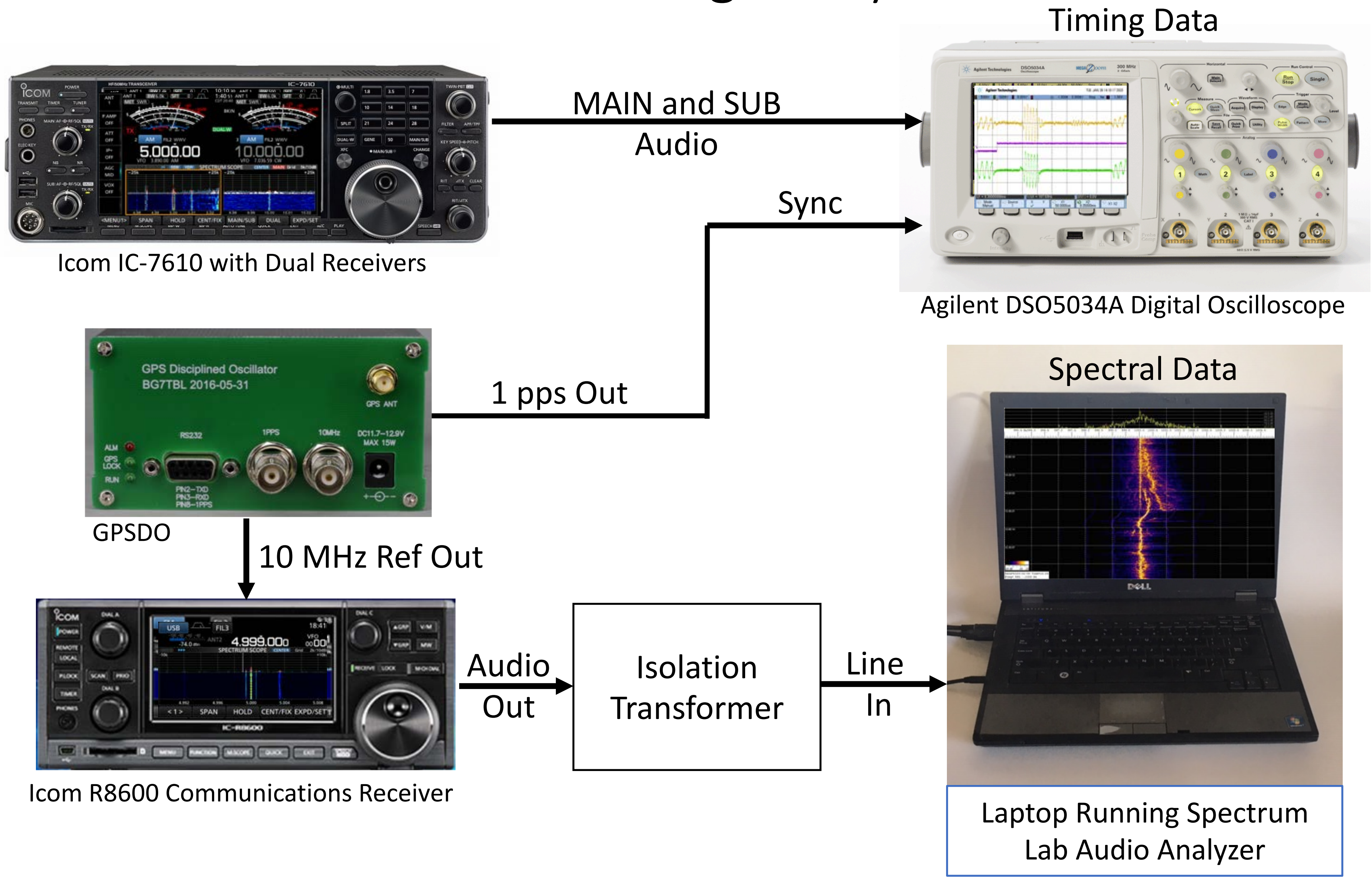
Published Timing Tick Information:
WWV – 5 cycles of 1000 Hz
WWVH – 6 cycles of 1200 Hz
Alternating 500/600 tone frequencies

A sync reference can be obtained from the 1 pps output from a GPSDO.

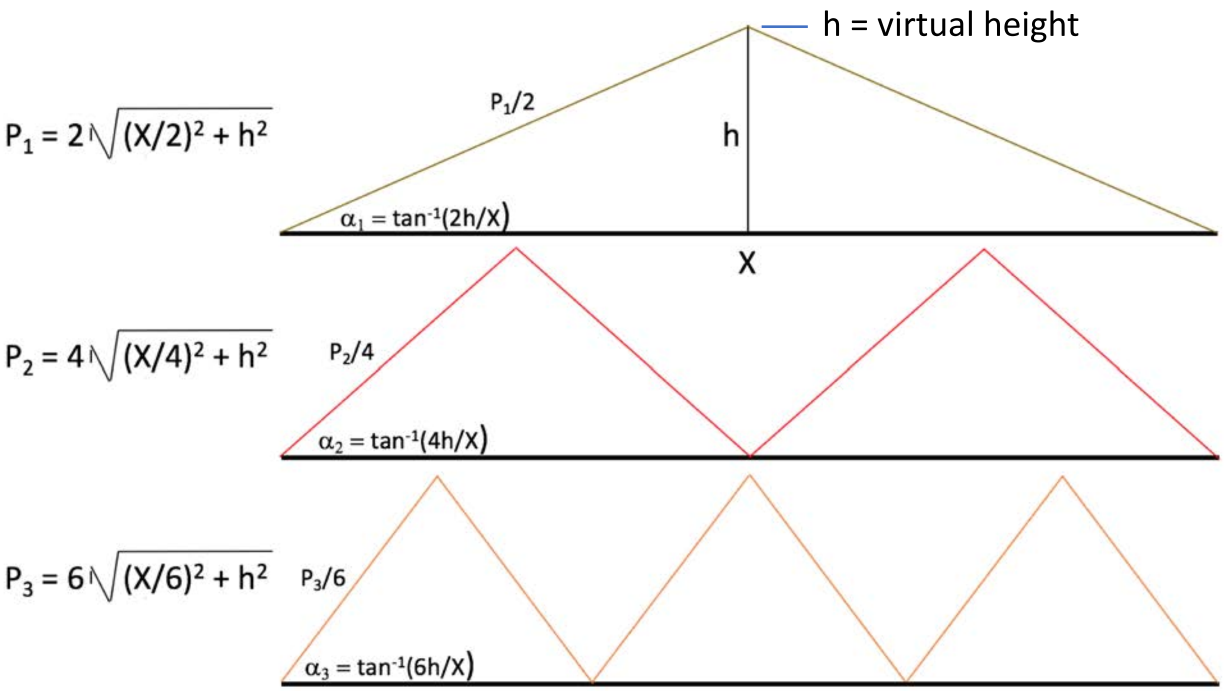


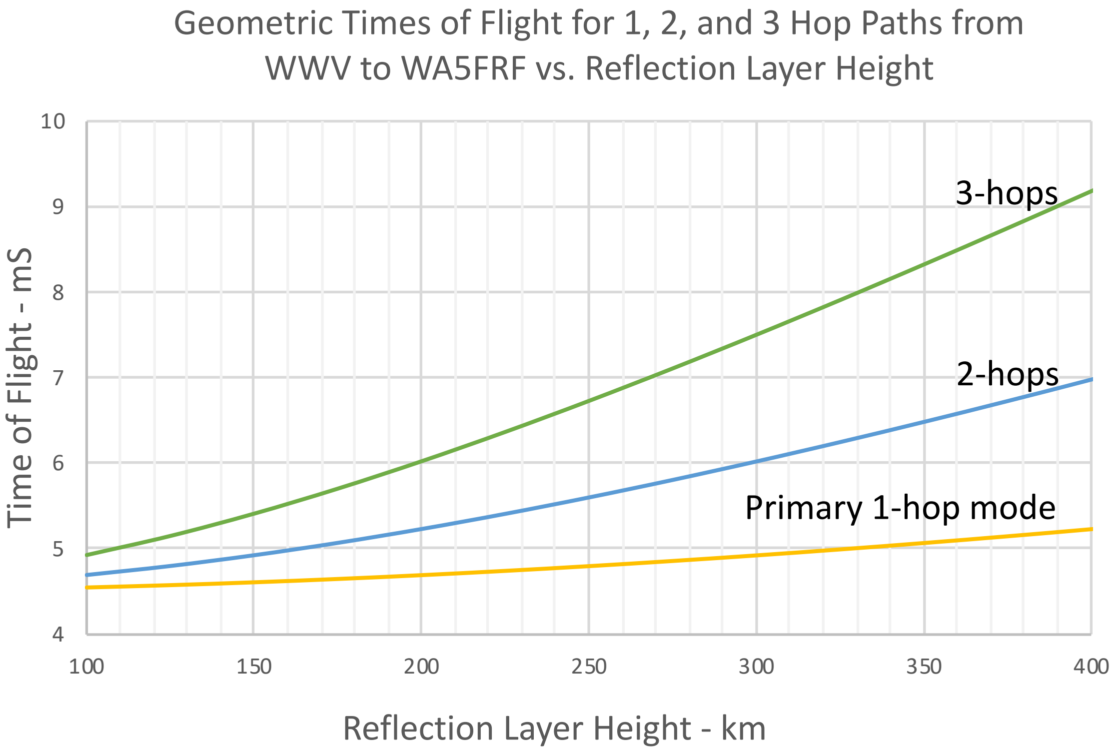
On-the-air reception of WWV and WWVH Timing Ticks At WA5FRF. Time difference of arrival is ~17mS. WWV at 1350 km, WWVH at 6050 km great circle dist.

Instrumentation Used for WA5FRF Timing Study



Idealized Geometry for 1, 2, and 3 Hop Paths Used to Approximate Expected Pulse Timing





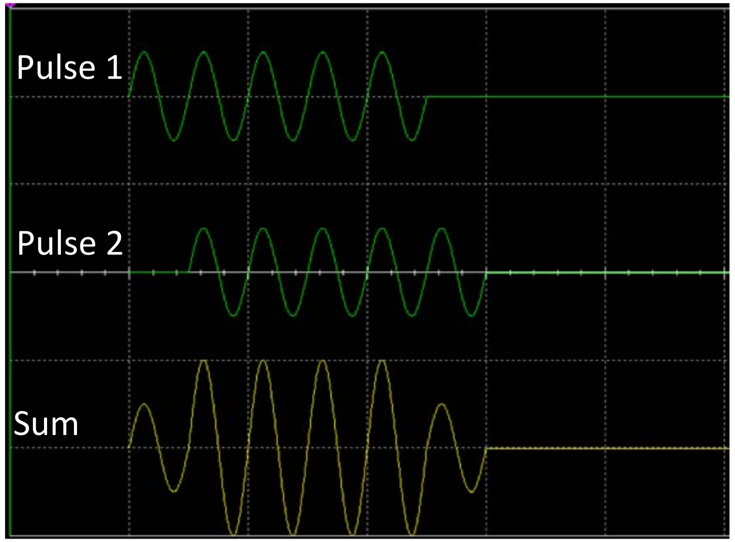
Simplifications:

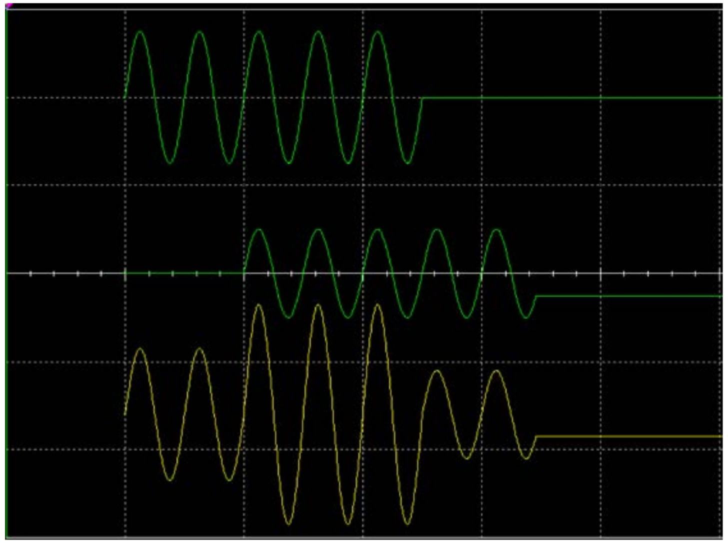
1. "Flat Earth" 2D geometry
2. Perfect reflections at constant virtual height
3. Constant wave speed = c

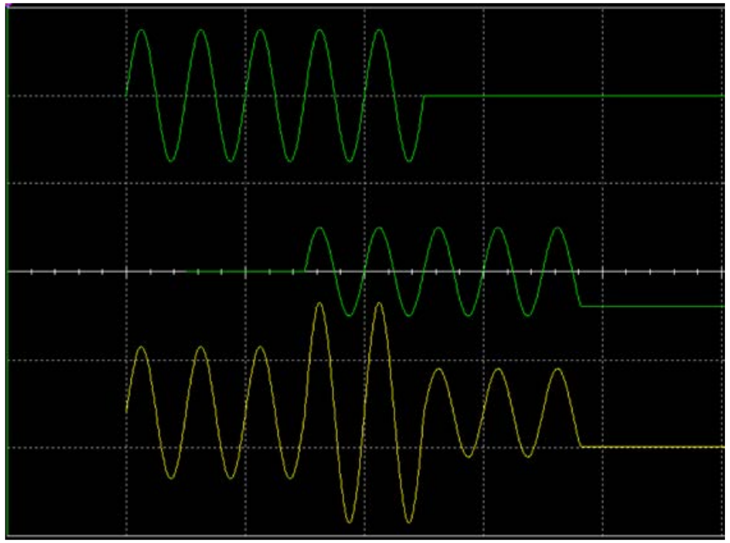
For ground distance (X) of 1350km and reflection heights (h) from 150-300kM, the differences in arrival times between the 1 and the 2 & 3 hop modes range from 0.3 to 4 milliseconds. This means the 2-hop and 3-hop pulses will come down within the 5 mS Primary pulse length, resulting in superposition.

The Time Delays Between Multiple Modes are Less Than the Pulse Width. Therefore the Primary and Delayed Pulses Overlap, Lengthening the Pulse by Superposition.

Simulated





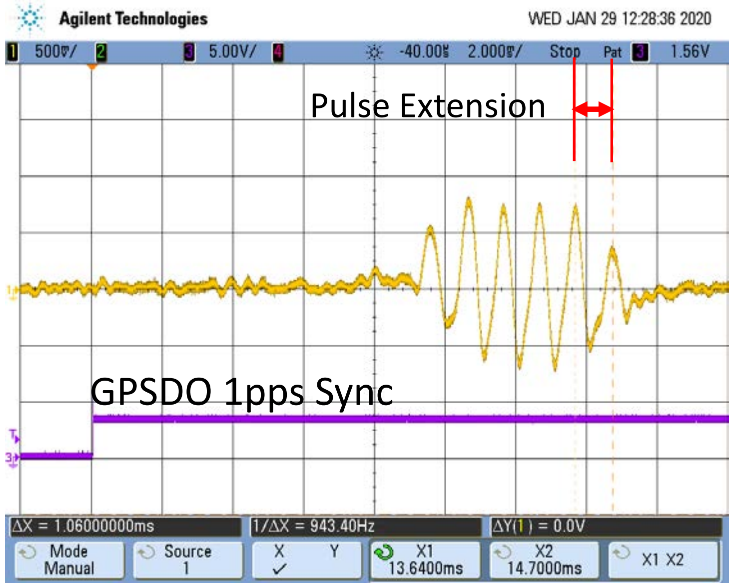


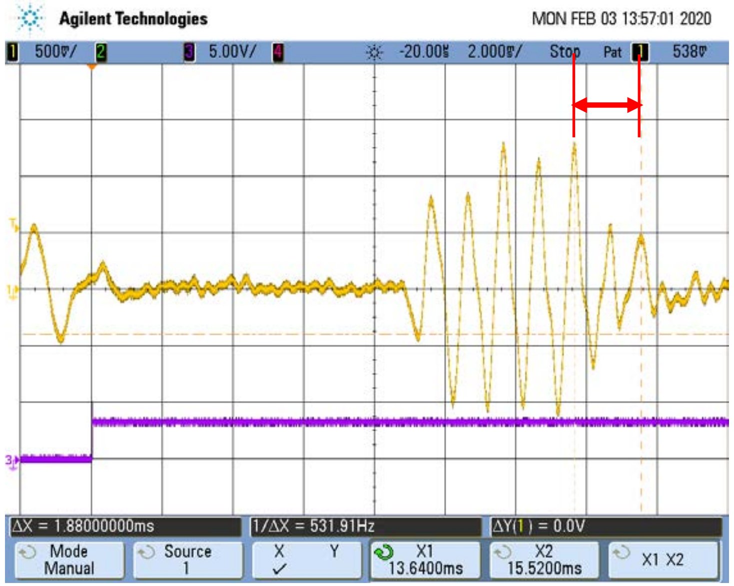
1 mS Delay -> 6 cycles

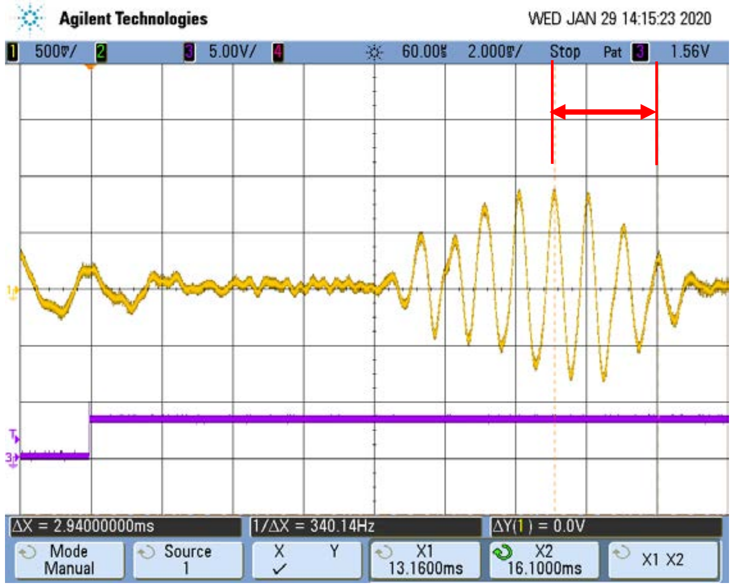
2 mS Delay -> 7 cycles

3 mS Delay -> 8 cycles

Measured

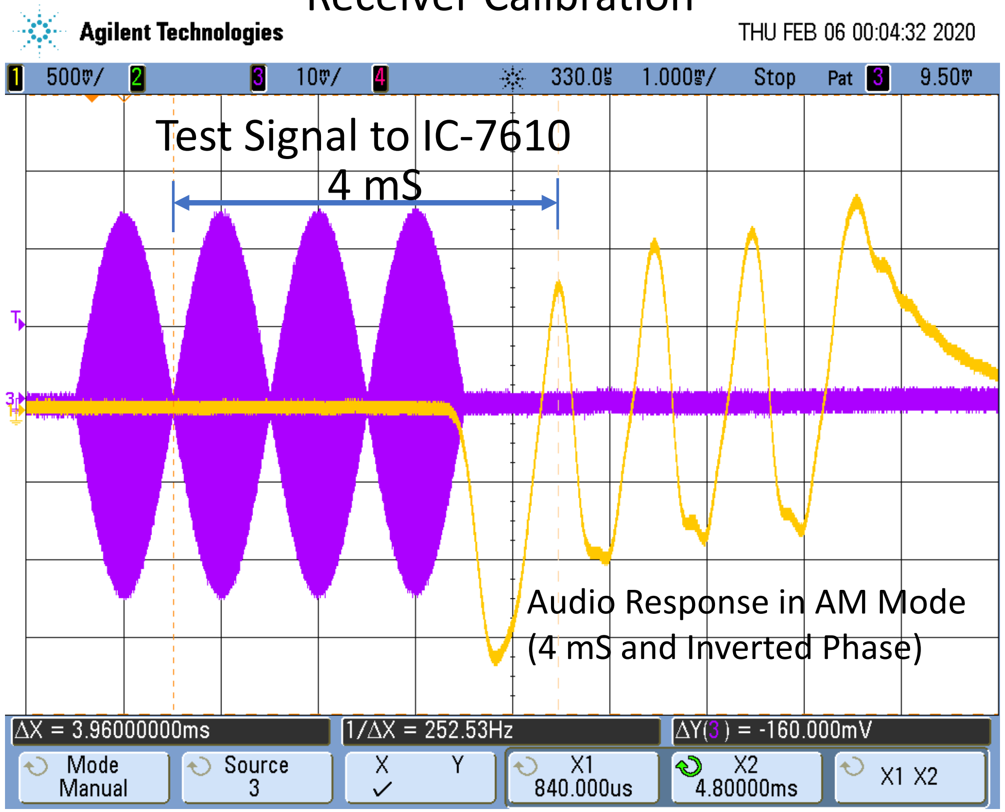




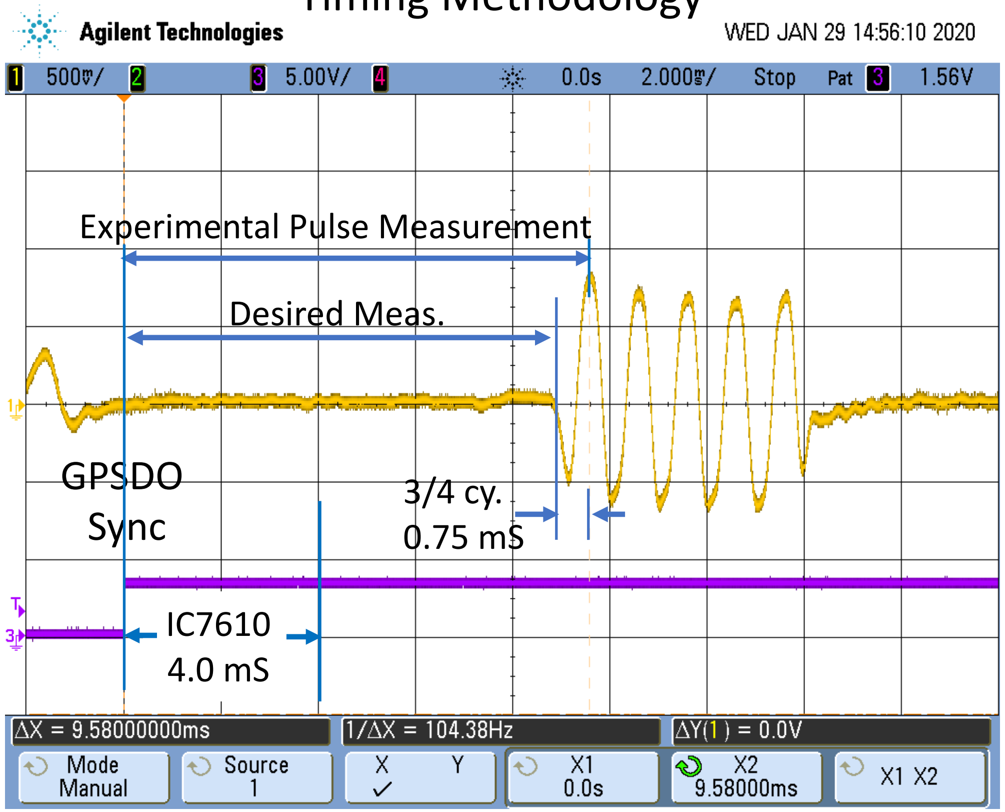


Arrival of Primary Pulse Measured as Difference Between GPSDO Reference and Middle of First Positive Cycle After Subtracting 4.75 mS Receiver Delay

Receiver Calibration



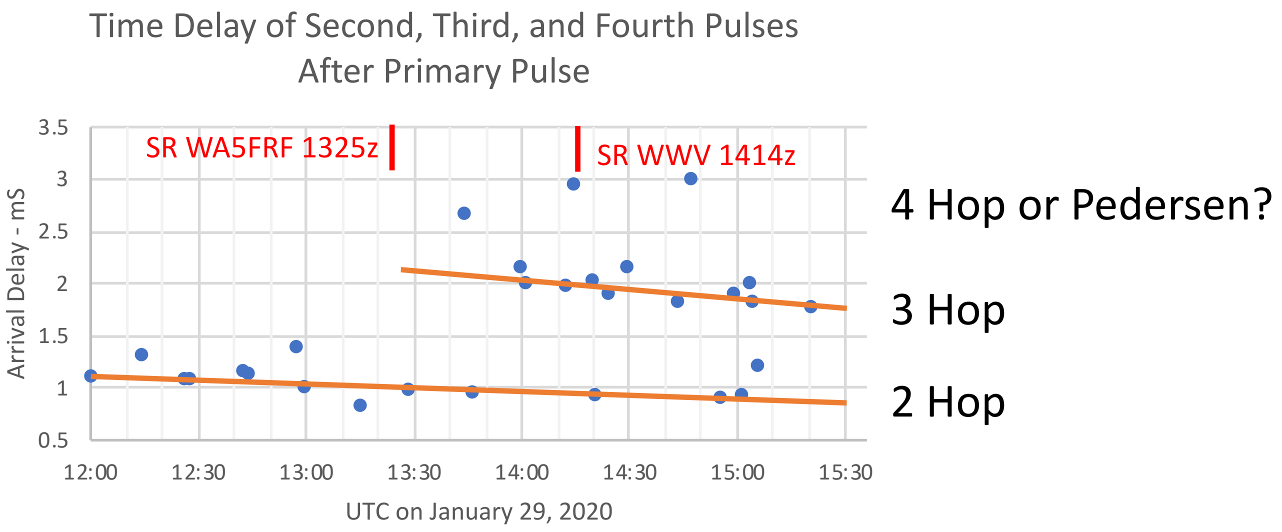
Timing Methodology

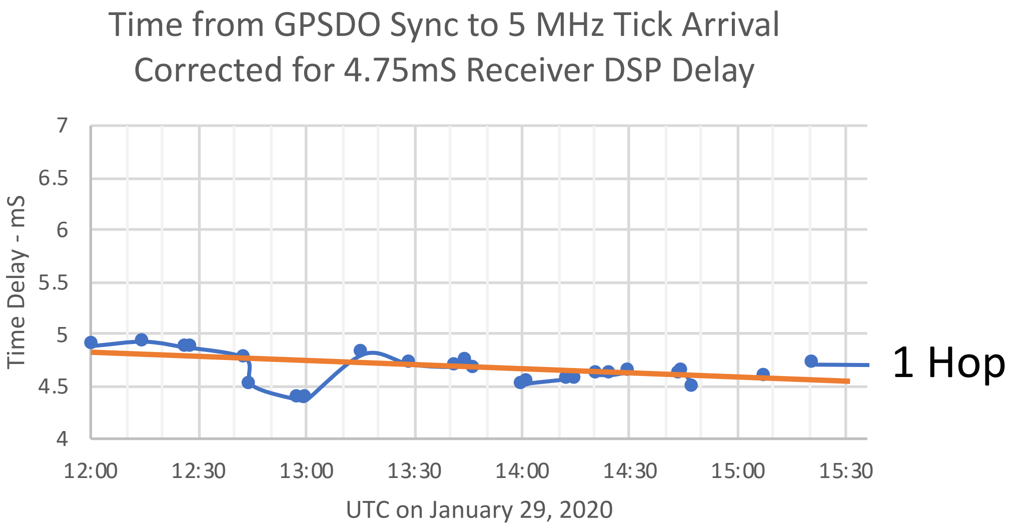


N.B. IC-7610 audio output is inverted in phase so the first received half cycle is negative going. But this half cycle is often weak and malformed. Therefore Primary Pulse arrival measurements were obtained my measuring to the middle of the first positive half cycle. This point is delayed by ¾ of a cycle from actual start of pulse, thereby adding another 0.75 mS to the receiver delay. Final timing correction used was 4.0 + 0.75 = 4.75 mS.

Measured Timing of Fundamental and Delayed Copies of 5 MHz WWV 1-sec Time Ticks on January 29, 2020

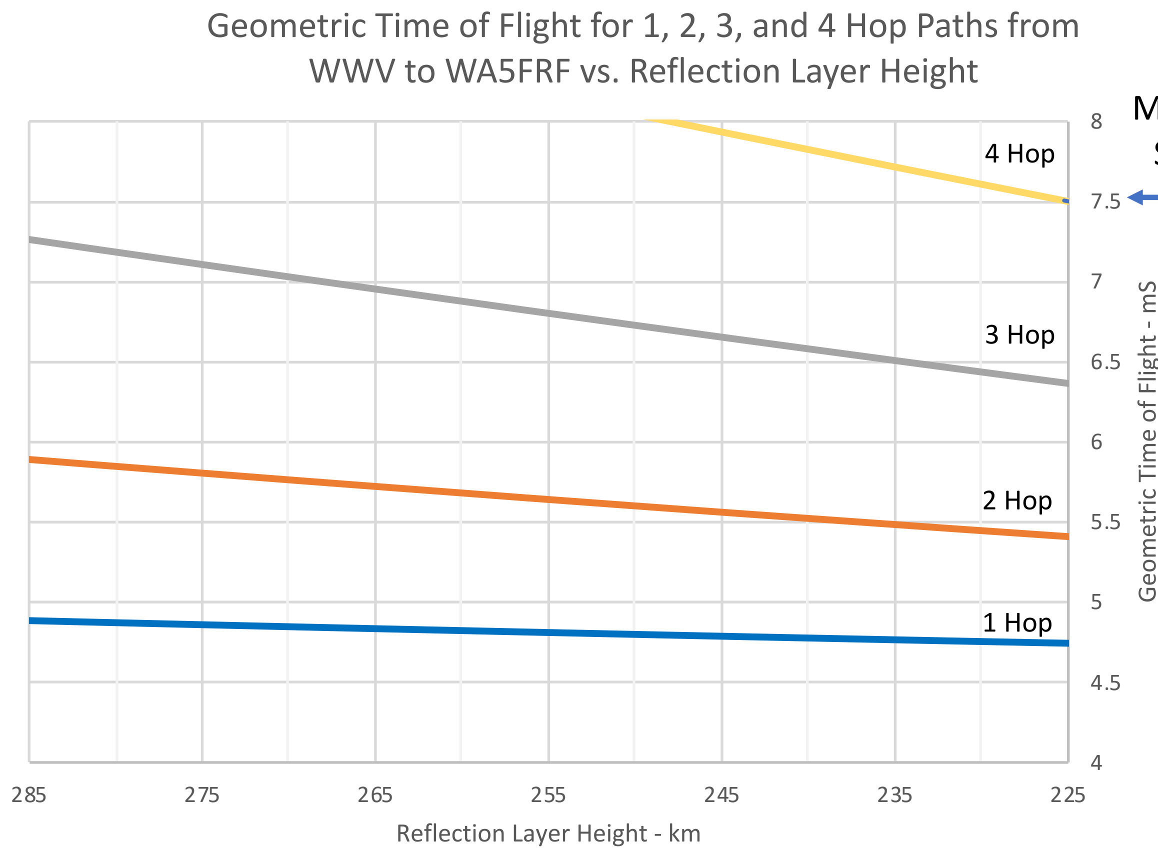
- Clustering of arrival times in overtone progression is consistent with multiple hop modes.
- Negative slopes are consistent with decreasing path lengths from descending ionization layer.

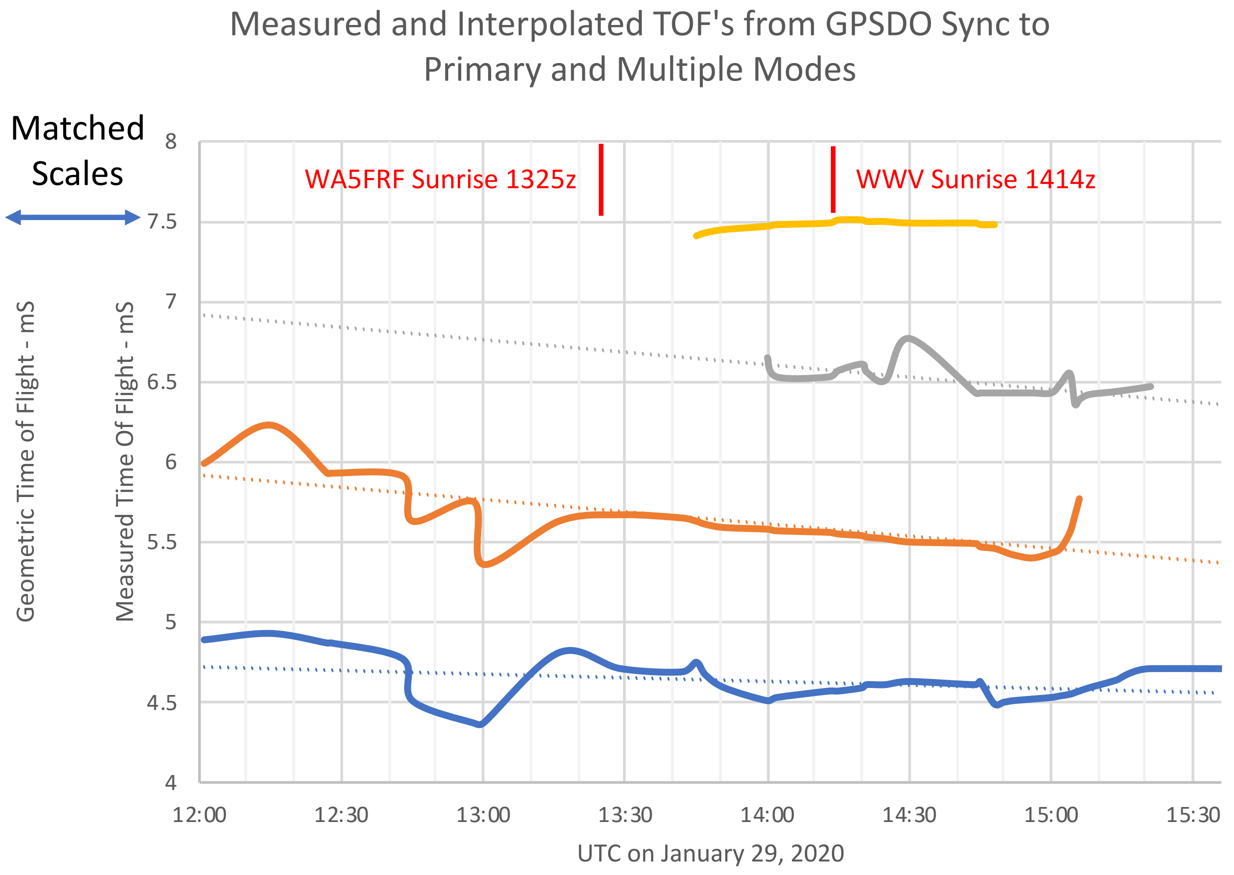




Actual arrival times of second and third delayed pulses can be estimated by adding the delay times in the top graph to the Primary arrival times in the bottom graph.
Effective virtual height descent rate available from slopes.

Comparisons Between Theoretical Geometric and Measured TOF's Suggest Delayed Pulses Are from Multiple Hops



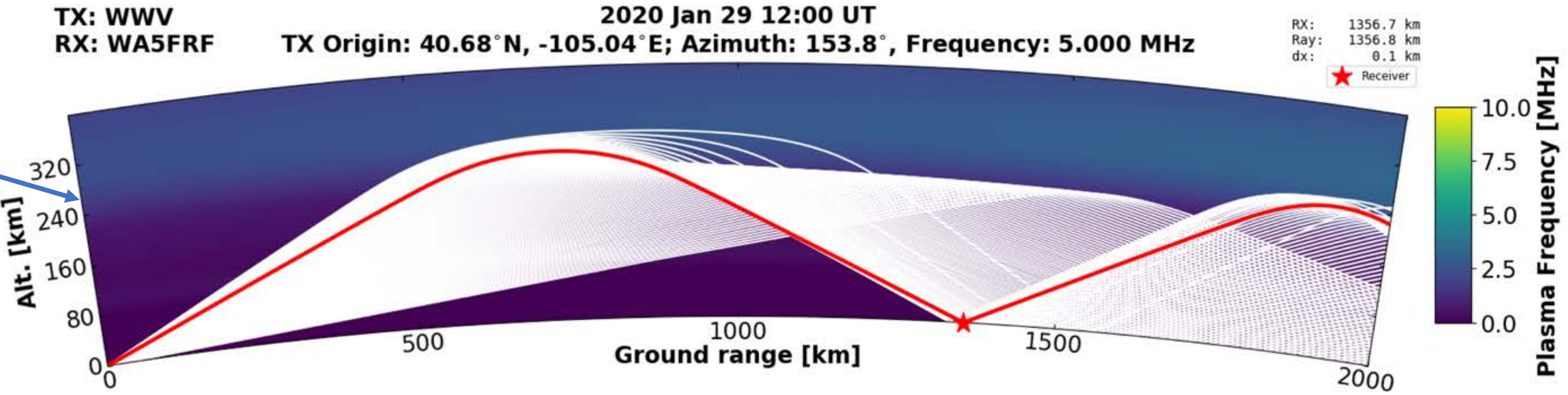


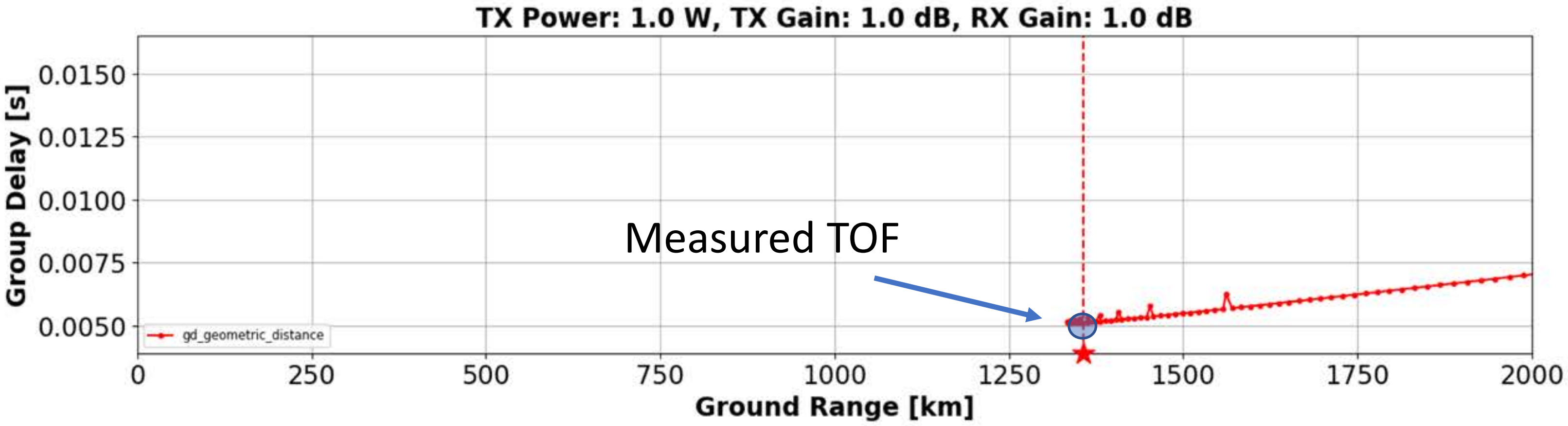
Geometric Times Of Flight plotted in descending order and cropped to approximately match measured data.

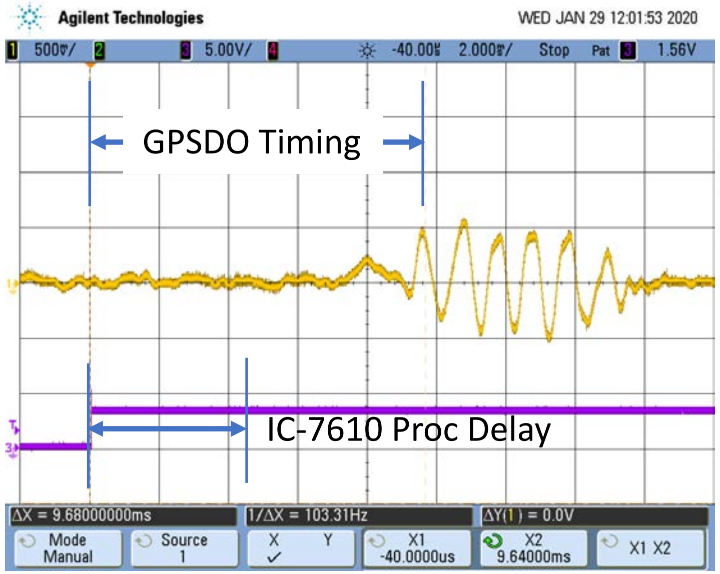
Measured 1-Hop Arrival Time is Consistent with Single Hop PHaRLAP Ray Trace Modeling

PHaRLAP Simulation Data Provided by Nathaniel Frissell W2NAF

Refraction height inferred from idealized geometry consistent PHaRLAP prediction.







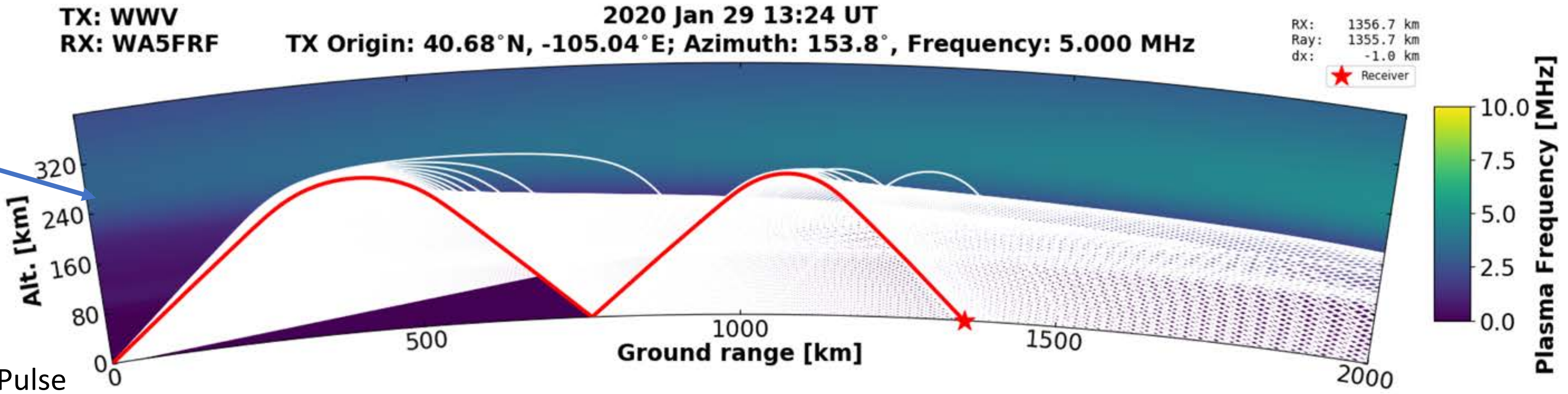
Measured Data

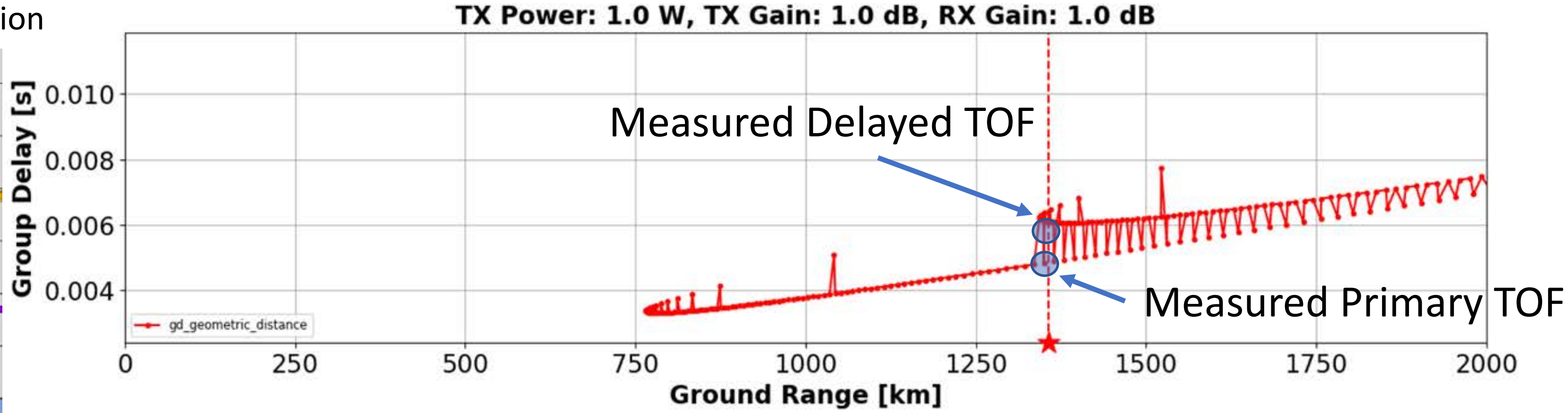
Predicted group delay near 5 mS consistent with measured arrival time of 4.93 mS for primary 1-hop mode at 1201z. T = 9.68 (GPSDO) – 4.75 (IC-7610) = 4.93 mS.

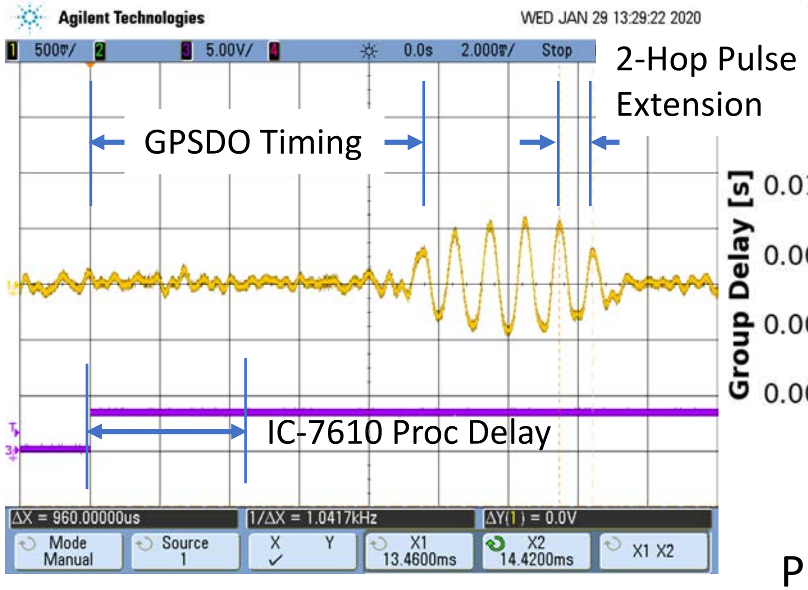
Measured 2-Hop Arrival Time is Consistent with PHaRLAP Ray Trace Modeling

PHaRLAP Simulation Data Provided by Nathaniel Frissell W2NAF

Refraction height inferred from idealized geometry consistent PHaRLAP prediction.



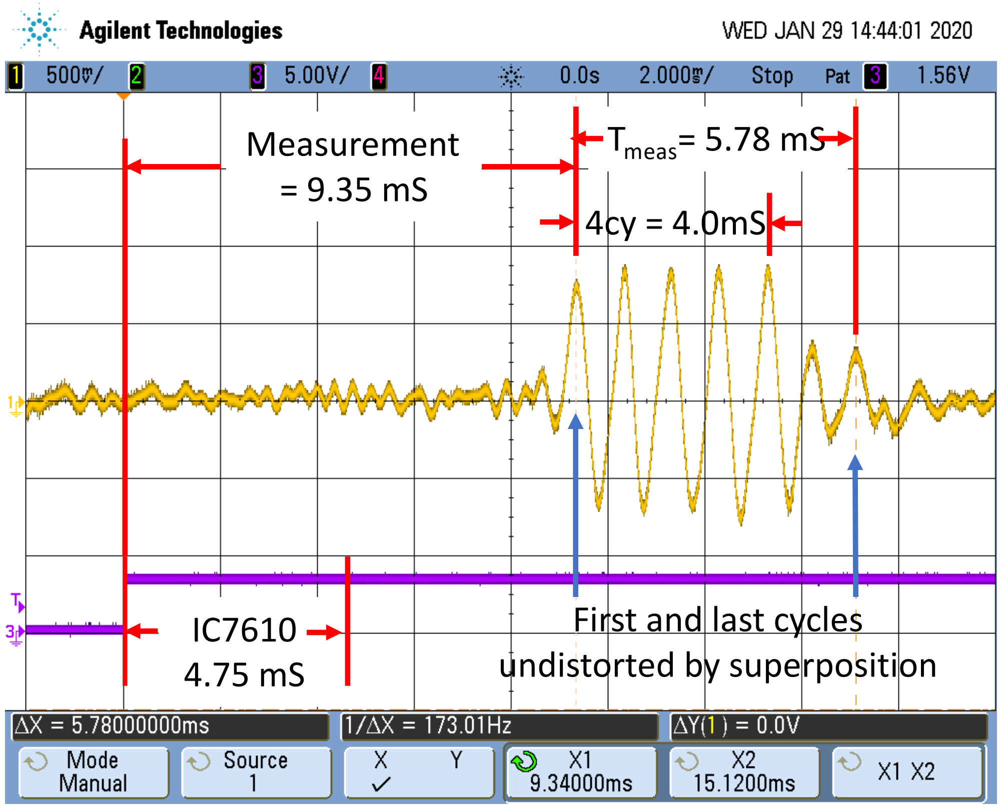


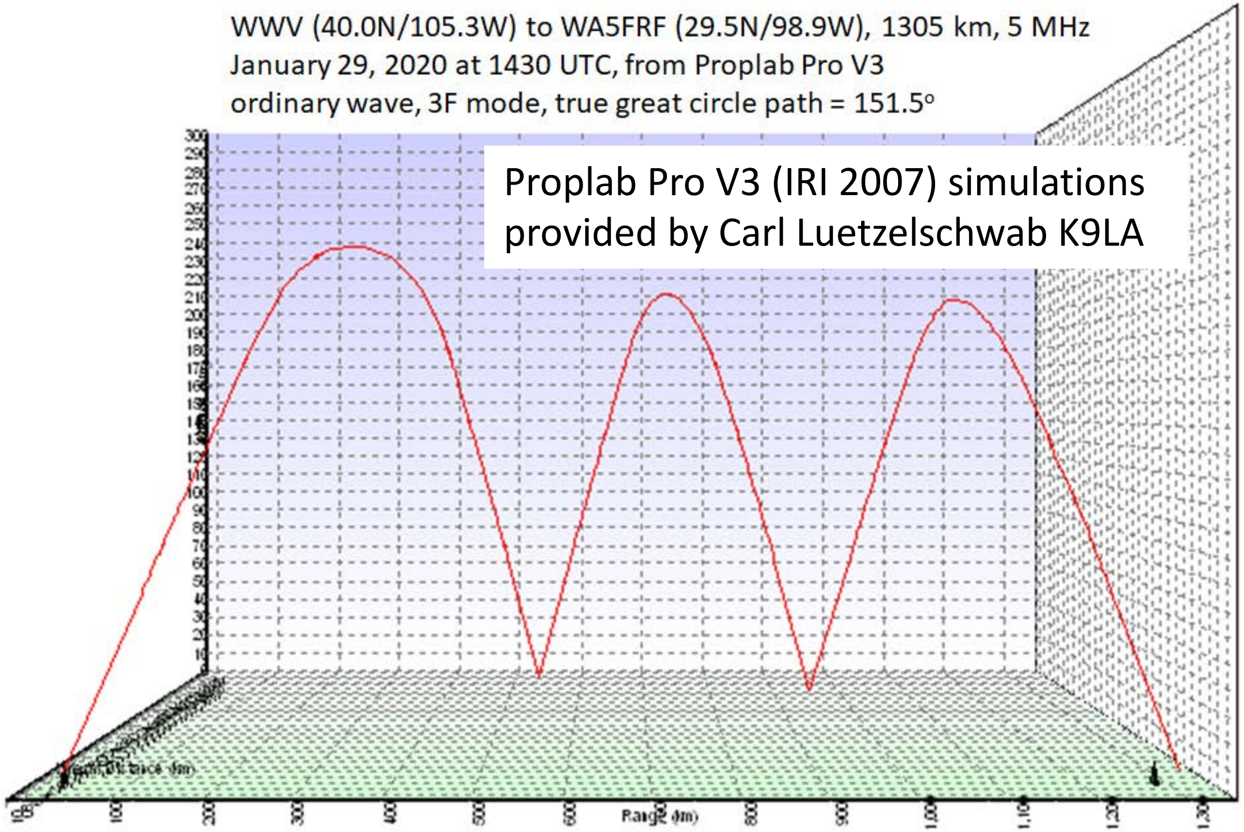


Measured Data

Predicted group delay near 6 mS consistent with measured 2-hop arrival time of 5.67 mS at 1329z. T = 9.46 (GPSDO) – 4.75 (IC-7610) + 0.96 (Extension) = 5.67 mS

Measured 3-Hop Arrival Time is Consistent with 3F Proplab Pro 3D Ray Trace Modeling





N.B. A better measurement technique is to reference the leading cycle of the primary and last cycle of the delayed pulses since they are not distorted by superposition.

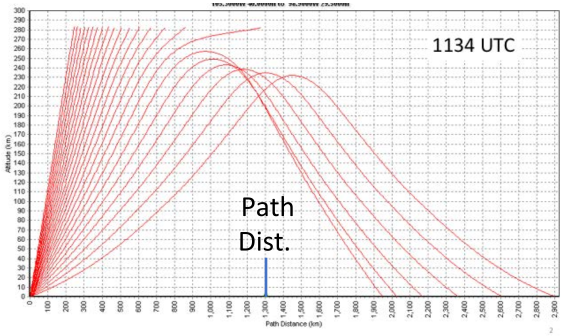
Measured 3F TOF = Leading Edge – IC7610 + T_{meas} – 4 cy

= 9.35 – 4.75 + 5.78 - 4.0 = 6.38 mS

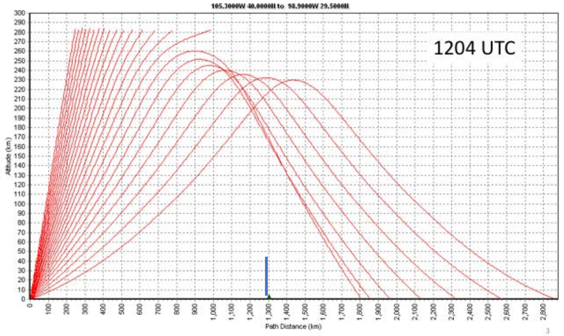
ray trace	mode	elev angle	az angle	total dist in km	time of flight assuming speed of light
3D	3F	49	143.3	1938	6.46 msec

Proplab Pro V3 (IRI 2007) simulations for 03/04/2020 provided by Carl Luetzelschwab K9LA

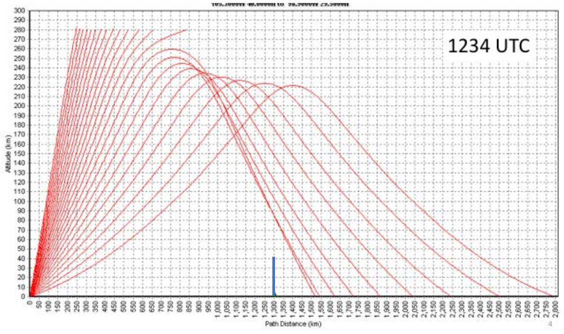
PropLab Simulations During Dawn Transition Show Opening of Multiple Hop Modes at Multiple Heights and Angles



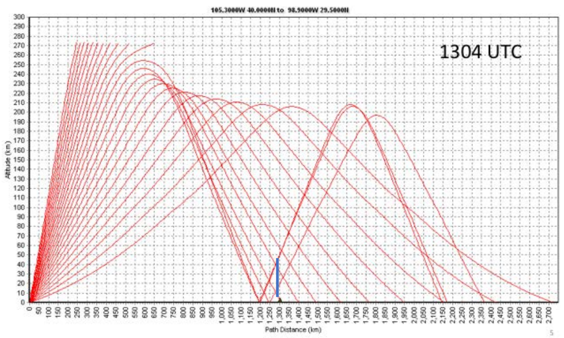
SR - 2.5 hr.



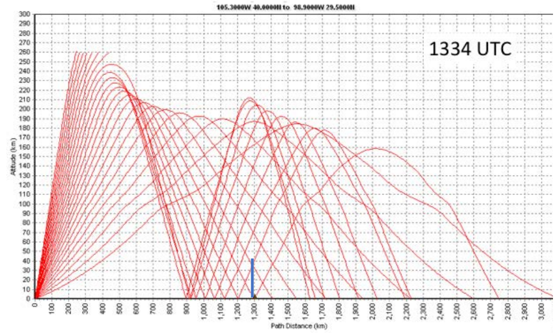
SR - 2 hr.



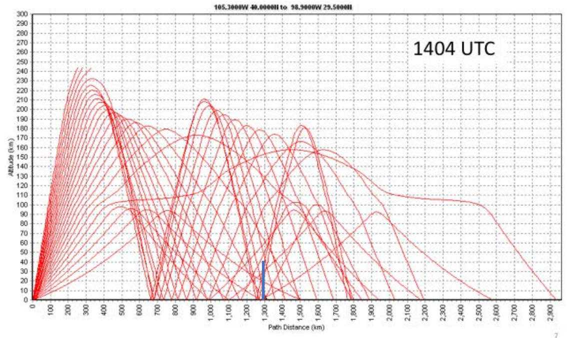
SR - 1.5 hr.



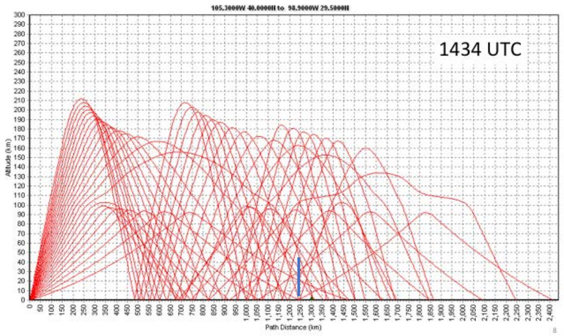
SR - 1 hr.



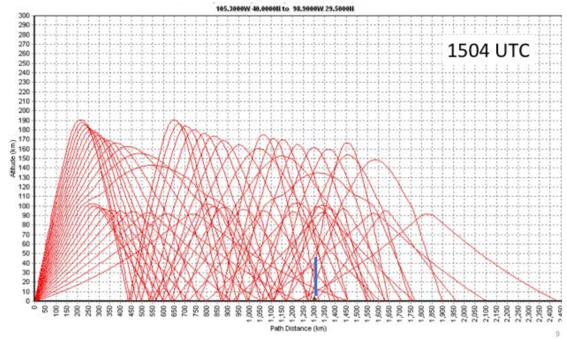
WA5FRF Sunrise



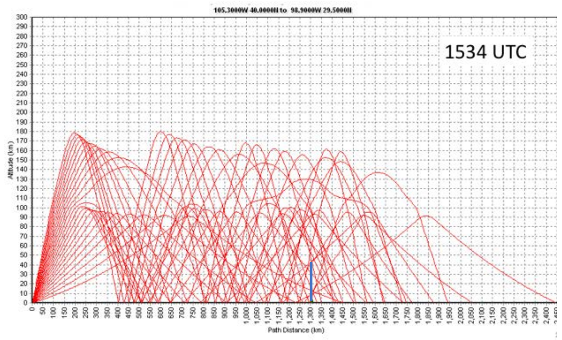
Mean Sunrise



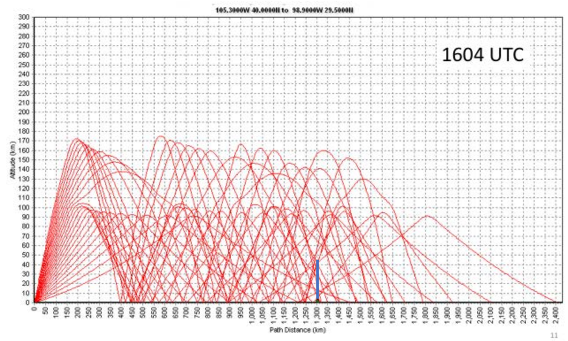
WWV Sunrise



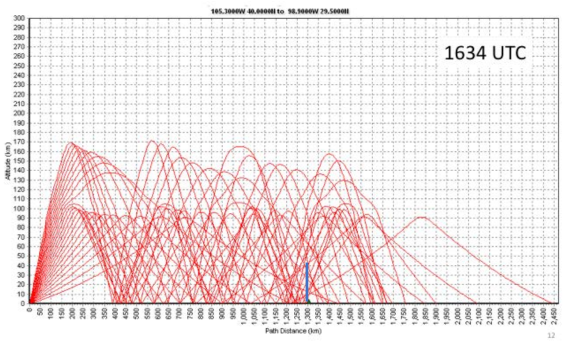
SR + 1 hr.



SR + 1.5 hr.



SR + 2 hr.



SR + 2.5 hr.

Observation Summary and Recommendations

- Timing data was acquired on primary and delayed copies of timing ticks over a WWV-WA5FRF path. The data was observed to cluster in modes that were consistent with several aspects of multiple mode propagation during the dawn transition.
- The best demodulator evaluated was Synchronous AM (S-AM) on an R-8600, followed by a standard non-coherent AM detector. There are many times when the carrier disappears due to selective fading resulting in severe pulse distortion. S-AM can recover some, but not all of these waveforms. SSB demodulators are immune to carrier fading but are not phase-locked with the WWV carrier. A rolling phase characteristic results. Receivers (especially SDR's) must be calibrated for processing delay. Throughput delay is affected by receiver make, demodulator type, and filter selection.
- The time delays between the primary and delayed copies over this path were less than the 5 mS pulse width, resulting in superposition. Best oscilloscope timing measurements can be made by referencing the start of the primary pulse to the end of the delayed copy because these regions are free from superposition distortion.
- The timing measurements reported here were obtained by manual measurements on oscilloscope recordings. Trace selection and interpretation were done by a human operator and therefore subject to bias. A more precise phase delay measurement may be possible through a Fourier or other analysis of the composite waveform. An automated collection and data extraction method would give more complete and accurate data and is recommended.
- The ability to detect true pulse onset is also limited by SNR. A good antenna in a noise free environment is crucial. A multiband dipole resonated to frequency with a tuner was used in this study.
- Receiver bandwidth can affect pulse appearance. Widest bandwidth (9 kHz in AM on the 7610) gave best shape preservation. Narrower bandwidth reduces noise but distorts the pulse shape and can change timing.
- Numerous characteristics of the measured timing data suggest the multiple frequency tracks during the dawn transition can be attributed to multiple modes of propagation. However the actual makeup and shape of the dawn transition spectrum is affected by many contributing factors. Analysis is a work in progress. Automated acquisition and analysis of timing data can be a valuable tool in deciphering these complex processes.