FST4W ON THE HF BANDS: *WHY - WHAT TO EXPECT - EQUIPMENT - RESULTS*

Gwyn Griffiths G3ZIL, Glenn Elmore N6GN, Rob Robinett AI6VN, Lynn Rhymes WB7ABP and John Watrous K6PZB

"*WSJT-X 2.3.0 introduced FST4 and FST4W, digital protocols designed particularly for the LF and MF bands*." Franke et al., Quick Start Guide.

We'll show several benefits from using FST4W on the HF bands.

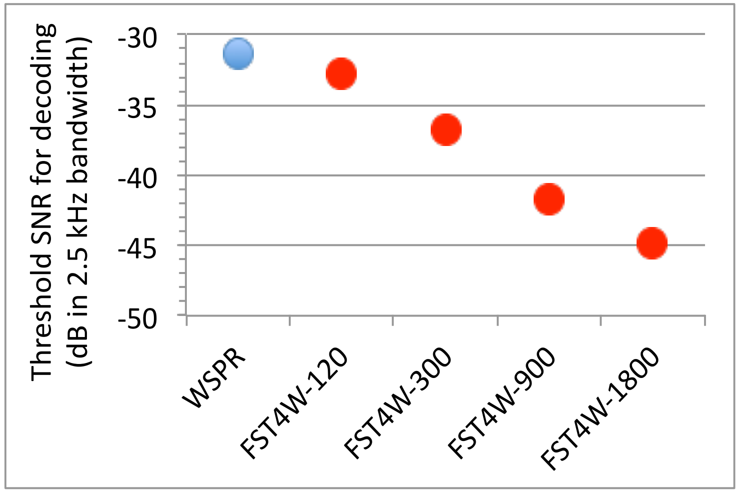
We are grateful to the Maritime Radio Historical Society (KPH) and Craig McCartney W6DRZ, Globe Wireless Radio Services and KFS Radio Club (KFS) for hosting KiwiSDR systems, the supporting infrastructure and the splendid antennas, and to JJ1BDX, KF6ZEO, KJ6MKI, KP4MD, WA2TP, WW6D, and ZL2005SWL.

wsprdaemon.org

gwyn@autonomousanalytics.com

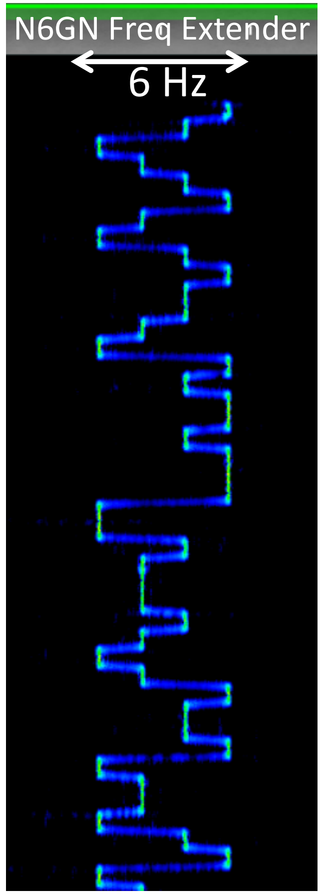
Why: The Nice to Haves

- Option of four sequence lengths: 120, 300, 900 and 1800 seconds
- FST4W-120 has:
  - Lower decode threshold, by about 1.4 dB, than WSPR
  - Higher tolerance to Doppler spread. At 2 Hz spread WSPR needs -17 dB SNR, FST4W-120 decodes at -24 dB SNR.



Defined at 50% probability of decode with Doppler spread of no more than 0.01 Hz

FST4W-120 33rd harmonic waterfall

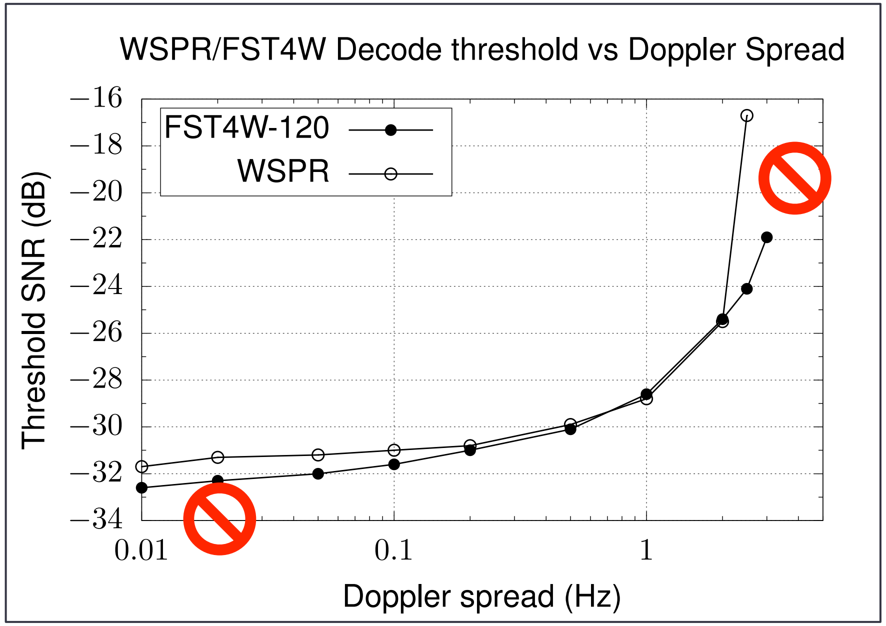


The Downside…

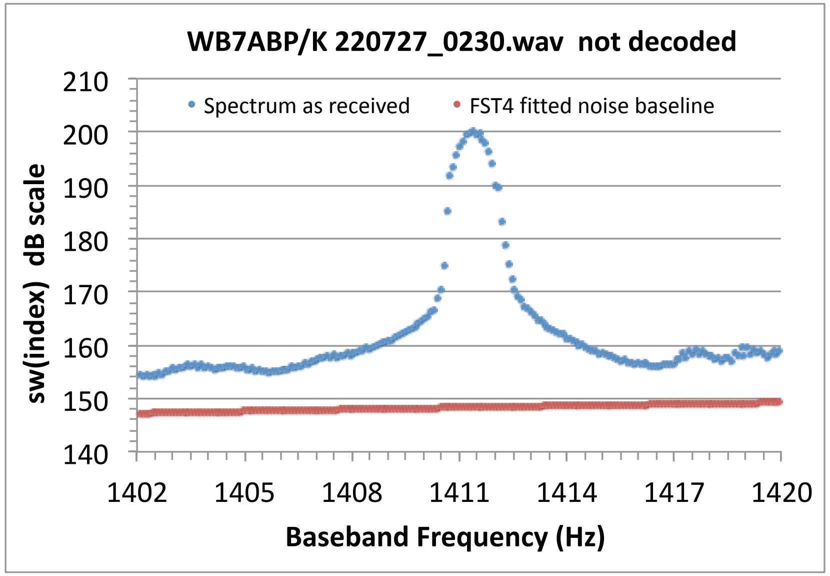
- WSJT-X sub-optimum for receive, one length at a time.
- Technical challenge: No drift compensation, tighter equipment spectral spread requirements.
- Physics challenge: Ionospheric Doppler spread, especially for longer sequence lengths and multi-hop paths.
- Few people transmitting and receiving at present.

Why: The Game-changer – Adds Spectral Width

- FST4W can measure spectral width if an empty file *plotspec* is present.
- Knowing spectral width:
  - Informs equipment needs.
  - Has already led to reduced KiwiSDR jitter and drift.
  - Makes it easier to judge if spot decode failed from low SNR or excess spreading.
  - May be a useful measurement of interest for ionospheric physics.

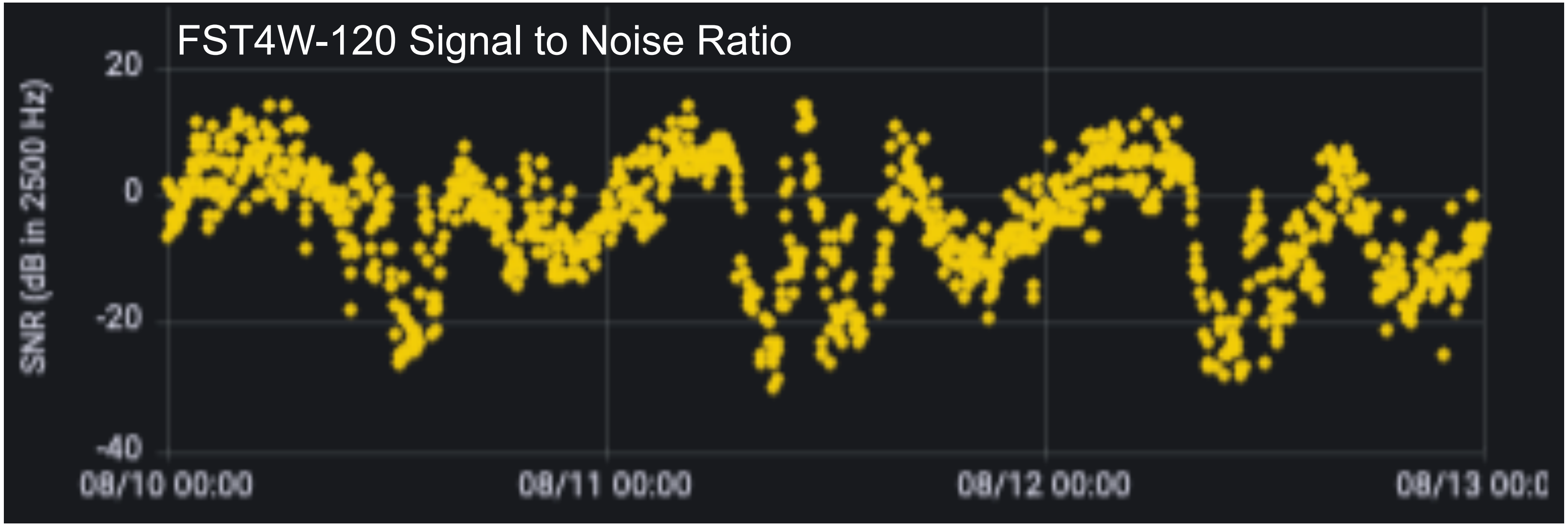


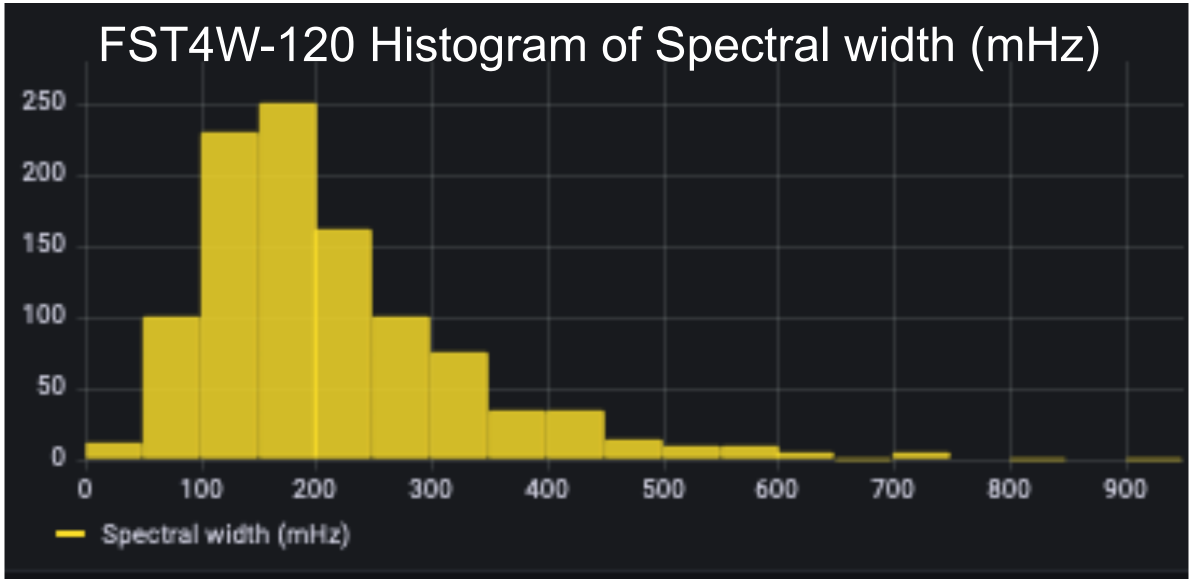
Courtesy Steve Franke



Example: 14 MHz FST4W-900 from N6GN Fort Collins to WB7ABP/K, Santa Rosa, not decoded – excess spectral spread.

What to expect: 14 MHz N6GN, Co. to AI6VN/KH6, Maui



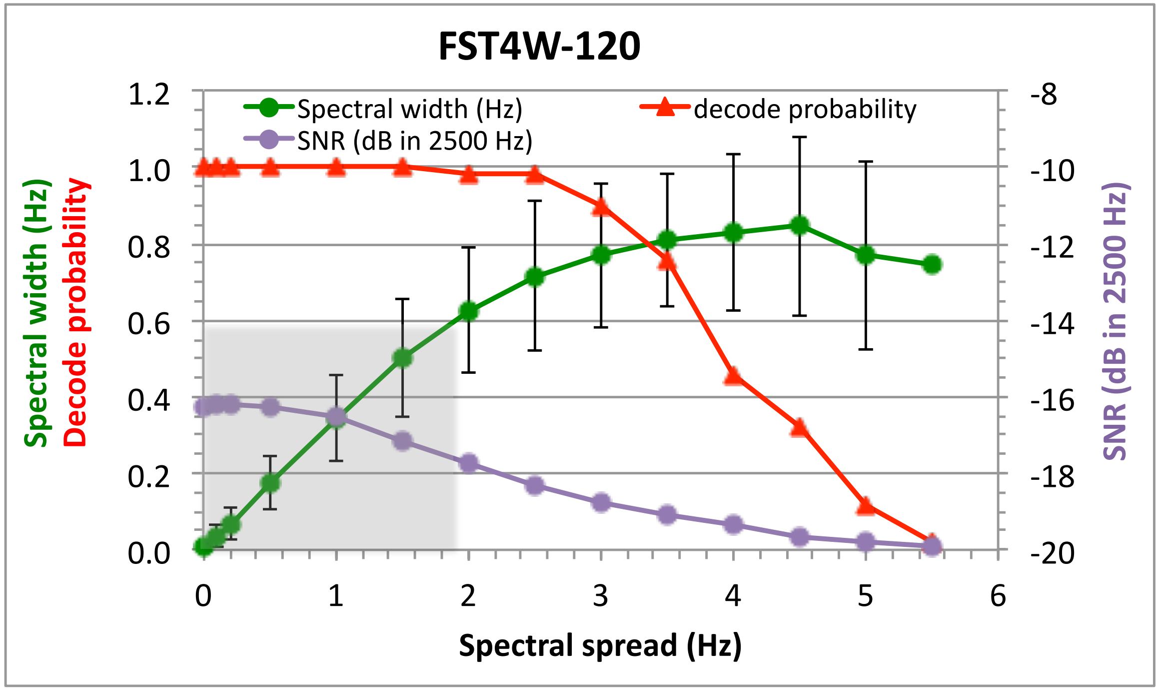


- 1032 spots received over three days.
- 5291 km path.
- Anan Angelia Tx with GPSDO.
- KiwiSDR Rx with standard* GPS frequency aiding.
- Mid-latitude Kp <3.

What to expect: Use of *fst4sim* simulator

WSJT-X contains an executable *fst4sim* that uses an ITU channel simulator model to predict performance given parameters including:

- Sequence length *TR*
- Time offset *DT*
- Doppler spread *fdop* −we treat as spectral spread from Tx, Rx and path.
- Differential path delay *del*
- Input *SNR*   *fst4sim "message" TR f0 DT fdop del nfiles SNR F*



Settings:

- *TR* 120 s
- *DT* 0 s
- *SNR* -15 dB
- *del* 1 ms
- *nfiles* 50

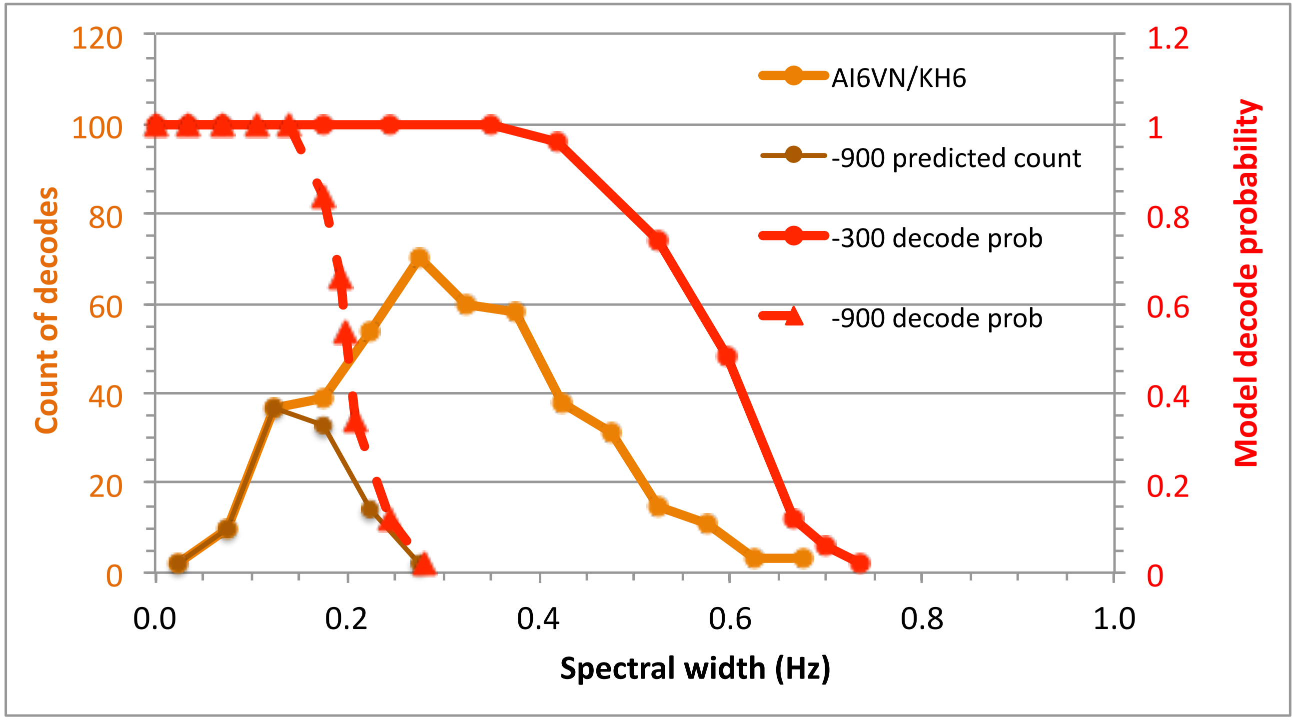
Run *jt9* for each Doppler spread in the graph, left. How many decoded out of 50 gives decode probability.

Output SNR decreases with Spectral spread.

N6GN->AI6VN/KH6 grey box

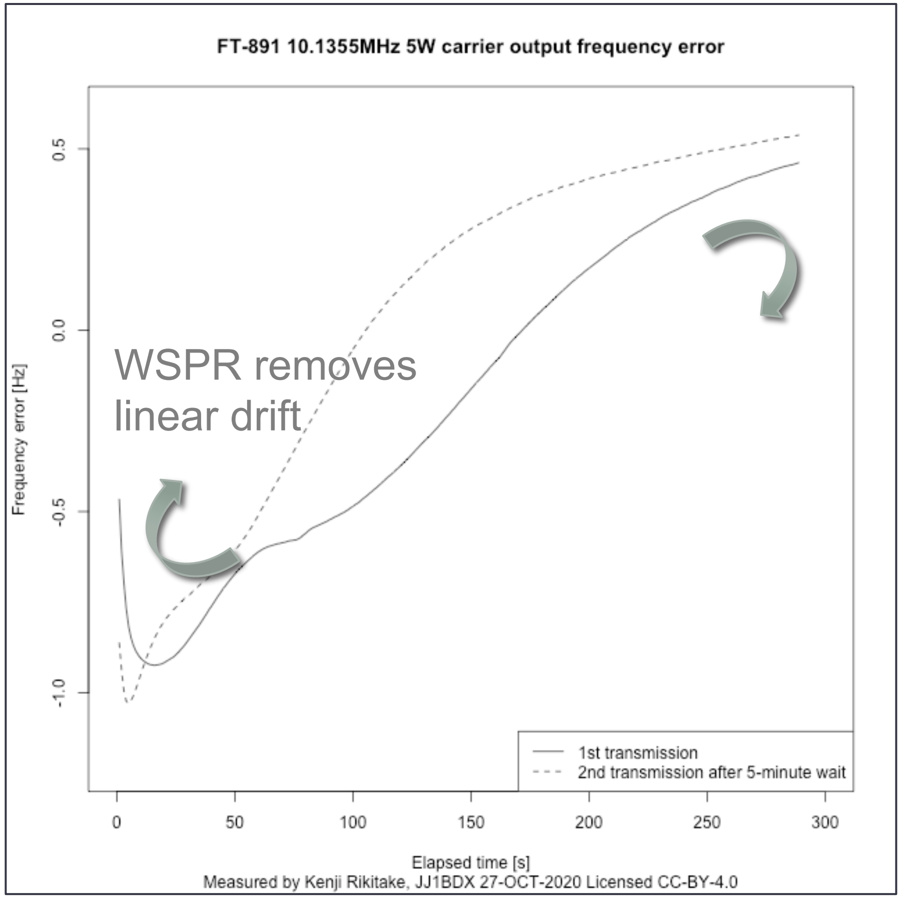
What to expect: Using *fst4sim* and spectral width results

- Use *fst4sim* probability of decode and measured spectral width for one sequence length to estimate performance at longer sequences.
- FST4W-300 N6GN to AI6VN/KH6 on 14 MHz – decodes reduced as spectral width extended into region of diminishing decode probability.



From FST4W-900 *fst4sim* decode probability (dashed red) and measured spectral width (orange) we'd expect few spots (brown) to be decoded over this path. In fact we received very few.

Equipment: Early tests on the HF bands disappointing

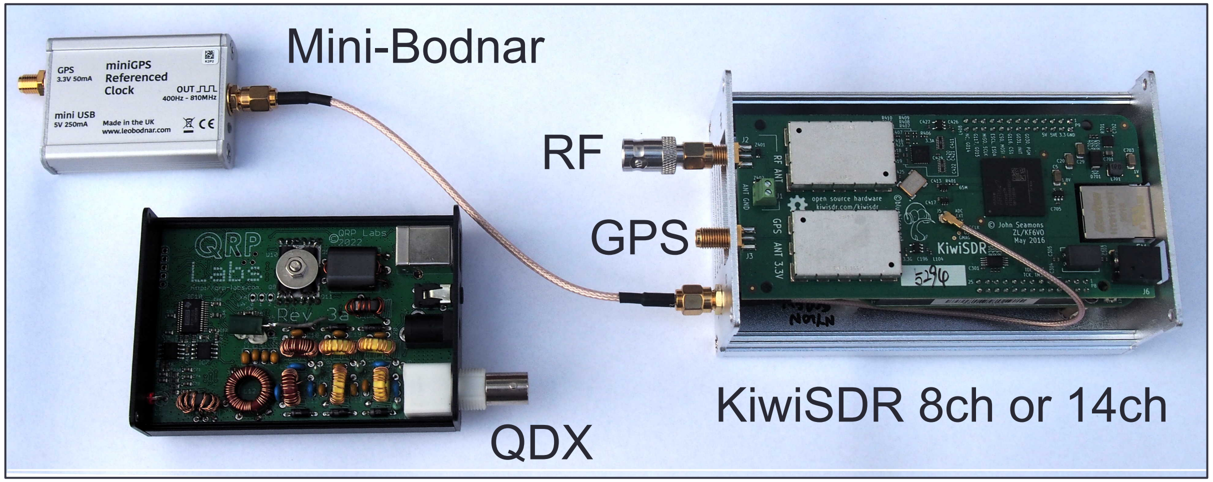


Graph used with kind permission

https://wsjtx.groups.io/g/main/message/17697
https://wsjtx.groups.io/g/main/message/17725
https://wsjtx.groups.io/g/main/message/17749

- Kenji Rikitake, JJ1BDX attempted FST4W-300 on 3.5, 7 and 10 MHz with an FT-891 transceiver for Tx and an Airspy HF Rx.
- FST4W-300 self-decodes were only possible on 3.5 MHz.
- FST4W-120 was possible on these bands.
- His measured drift during Tx is plotted left. The late Bill Somerville responded that FST4W does not remove linear drift.
- The receive side of transceivers can also be problematic. Temperature rise on Tx cycle may not be adequately compensated by TCXO over several following Rx cycles.

Equipment: What works for FST4W on the HF bands



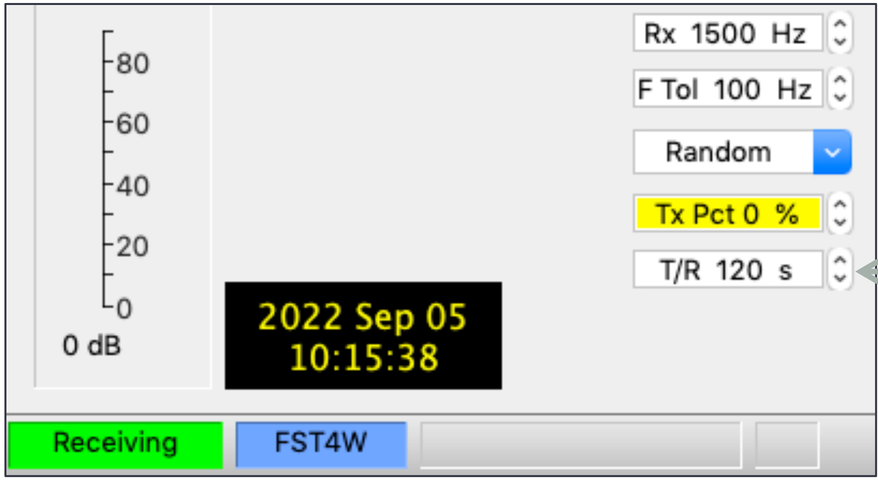
Transceive, use GPSDO

- ANAN ‘Angelia’ N6GN
- ANAN-10E K6PZB
- ANAN 100(D) WB7ABP

Receive

- KiwiSDR 8 ch or 14 ch (with BeagleBone AI), out-of-box GPS aiding or ext. 66.66 MHz GPSDO.
- ELAD FM Duo, ext. 10 MHz GPSDO, WW6D.
- QRP Labs QDX $69 digital modes transceiver, TCXO, receive only.

Software: WsprDaemon V3 – Practical FST4W reception



- WSJT-X requires you to select single sequence length to receive – here 120 seconds.
- Multiple WSJT-X instances needed to process and decode multiple FST4W lengths and WSPR.

```
declare WSPR_SCHEDULE=(
    "sunrise-01:00      G3ZIL_4,20,W2:F2:F5 G3ZIL_3,630,W2:F2:F5:F15
    "sunrise+01:00      G3ZIL_4,20,W2:F2:F5 G3ZIL_3,630,W2:F2:F5:F15
    "sunset-01:00       G3ZIL_4,20,W2:F2:F5 G3ZIL_3,630,W2:F2:F5:F15
    "sunset+01:00       G3ZIL_4,20,W2:F2:F5 G3ZIL_3,630,W2:F2:F5:F15
)
```

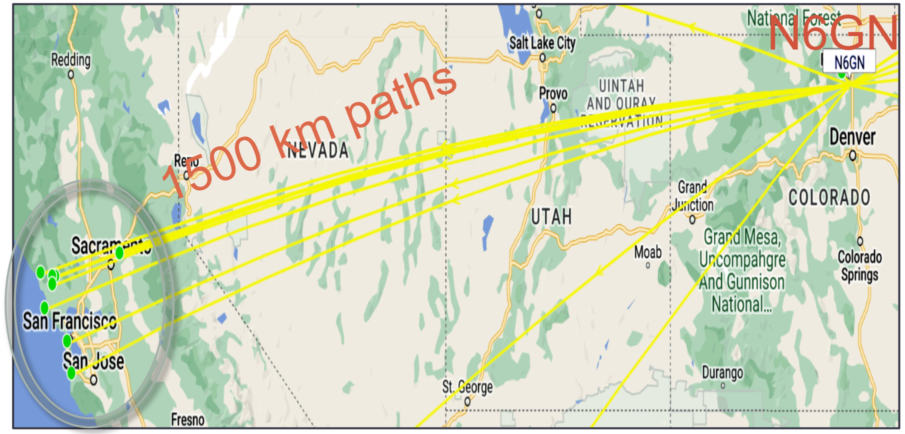
Obtaining Spectral Width and 0.1 Hz Frequency

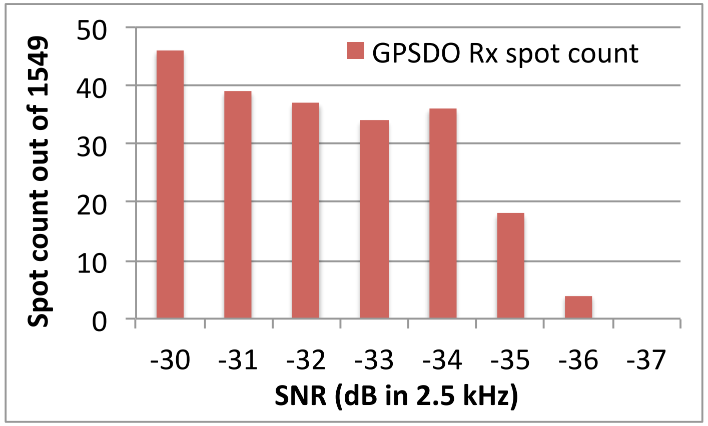
WSJT-X provides both enhancements if empty files *plotspec* and *decdata* are in certain directories.

WsprDaemon does this, and enhanced data is available in extended spots tables on WD servers

- Rob Robinett's WsprDaemon V3 allows multiple modes for each KiwiSDR and band. F2=FST4W-120 etc.
- Multiple modes on a band only need one KIwiSDR channel. One-minute wav files are concatenated for *wsprd* decoder for WSPR and *jt9* for selected FST4W lengths.

Results: FST4W-300 SNR <= -30 dB GPSDO *vs* KiwiSDR





Test null hypothesis of no difference in count of SNR <= -30 dB FST4W-300 spots decoded by receivers with phase-lock GPSDOs and standard KiwiSDR GPS aiding.
Phase-lock GPSDO Tx at 7 MHz at N6GN.
-36 dB SNR threshold at spread <=0.01 Hz 50% decode probability.

Experiment from 0400 UTC 08-31-22 to 1300 UTC 09-05-22 on 7 MHz.

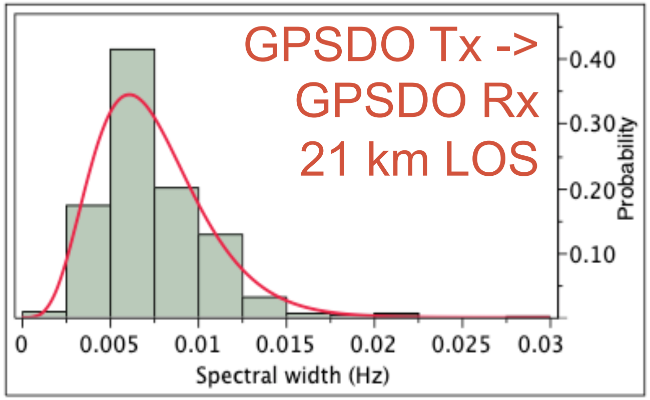
	Number of spots				
Phase-lock GPDSO:	42, 37, 38, 52, 45	Mean	43	stdev	6
KiwiSDR GPS aided:	17, 5, 15, 19	Mean	14	stdev	6

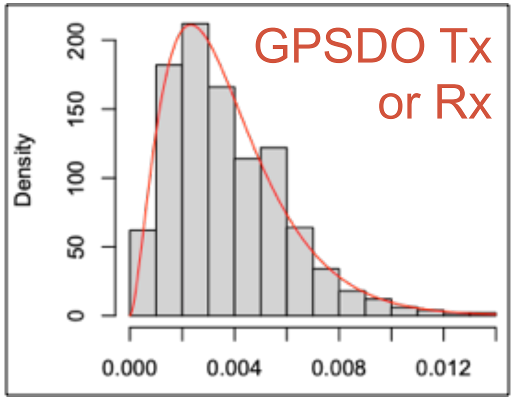
z statistic = 7 as > 2.58 we reject null hypothesis at 99% confidence, they are different.

Demonstrates nicely: Low Rx spectral spread gives best decode chance at low SNRs.

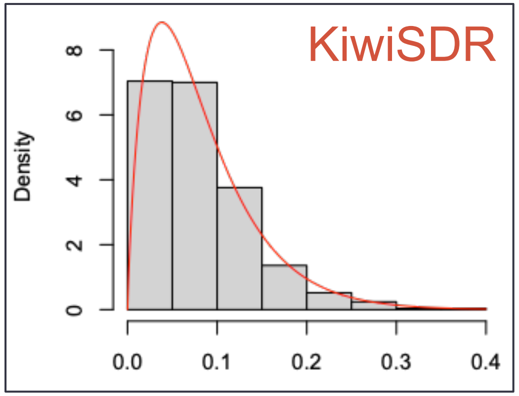
Equipment: Estimating equipment spectral spread

- **Setup:**14 MHz Tx and Rx 21 km apart, line of sight, with identical GPSDOs.
- **Step 1:** Gather FST4W-300 spectral widths. Plot histogram (total 543 spots).
- **Step 2**: Fit Gamma distribution, positive only, tail to right, red curve.
  Parameters: Shape 5.62, Scale=0.00132.
- **Step 3:** *Assume* zero path spread and Tx and Rx spread was 50:50.
- **Step 4:** Get separate Tx and Rx distributions by halving Shape, keeping Scale the same. In *R*:
  n6gn_tx<-rgamma(n=500, shape=2.81, scale=0.00132)
- **Setup:** 14 MHz GPSDO Tx and KiwiSDR Rx
  38 km apart, but over 1800’ hills.
- **Step 5:** Gather spectral widths. Plot histogram, fit Gamma distribution. *Assume* zero path spread.
- **Step 6**: Generate 500 random spreads from this distribution and from GPSDO Tx distribution, and subtract to *estimate* KiwiSDR spectral spread.





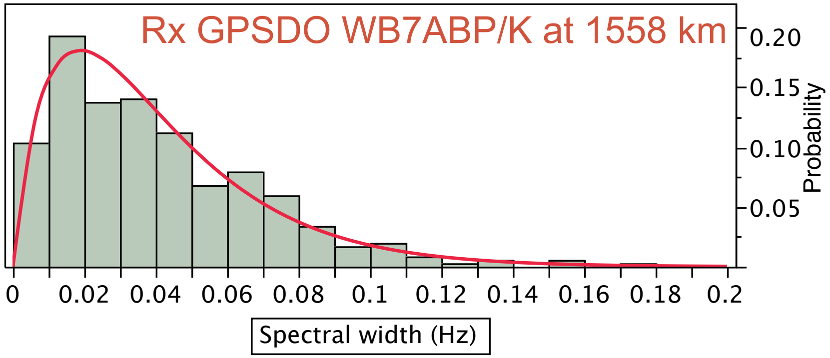
Mode at
0.003 Hz

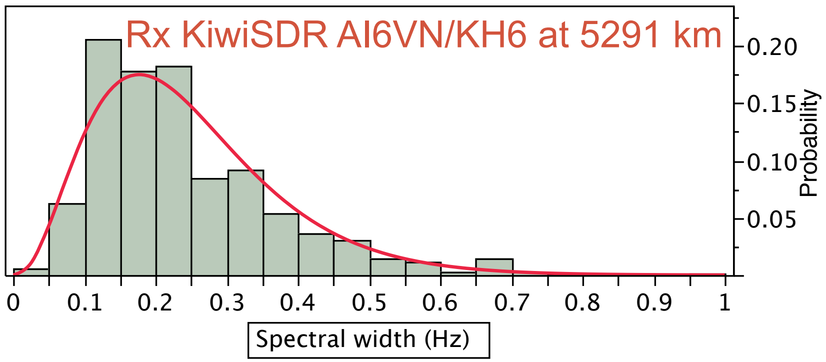


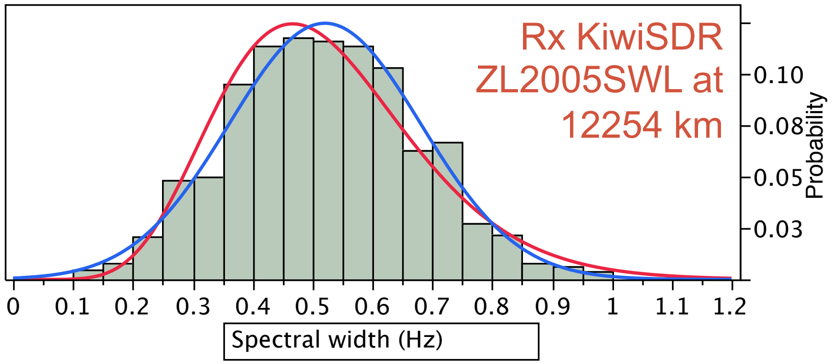
Mode at
0.050 Hz

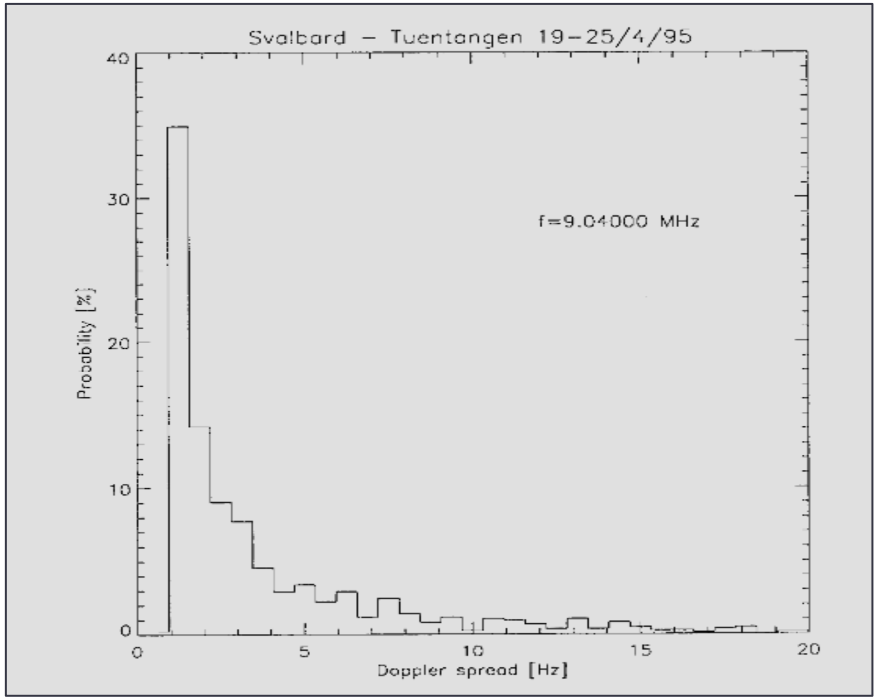
Results: Example Tx–Path–Rx spectral width histograms

FST4W-120 on 14 MHz with GPSDO Tx at N6GN, Colorado when Kp <3





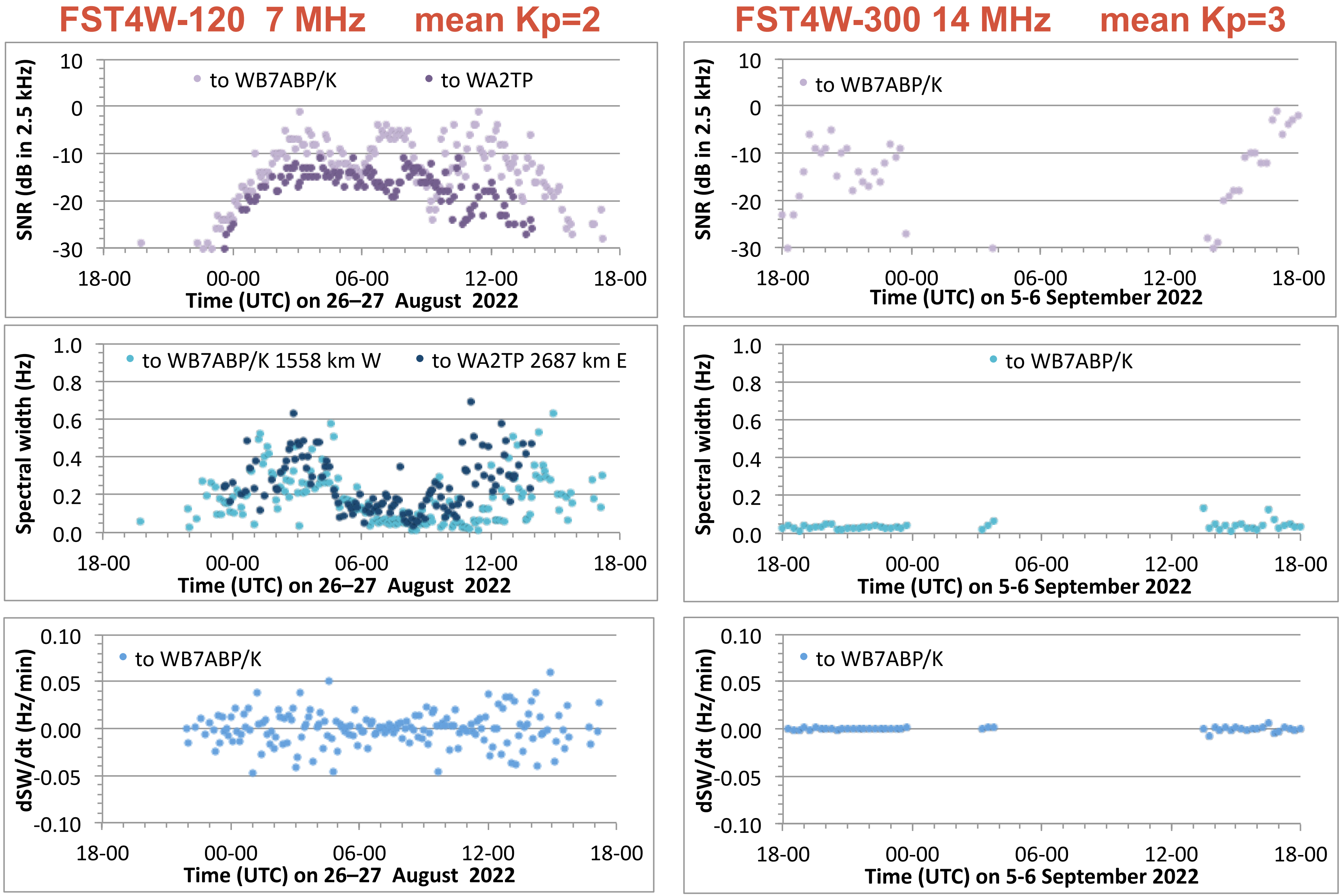




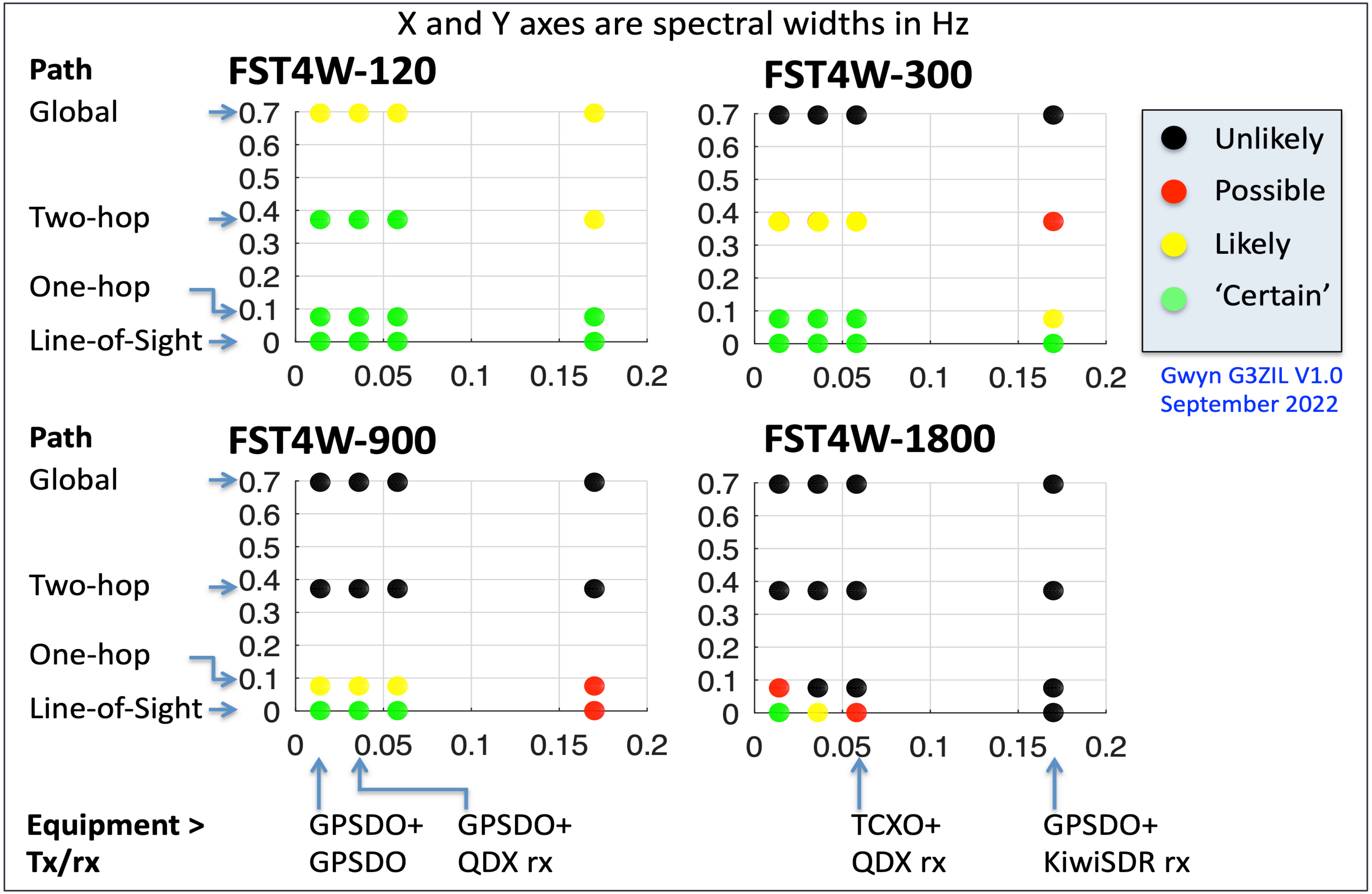
Doppler spread over 2017 km trans-Auroral Oval path between Svalbard and Tuentangen, Norway, April, 1995 at 9.04 MHz with 250 W.

Angling, M.J., et al., 1995. Measurements of Doppler spread on high latitude HF paths. In Proc. AGARD Sensor and Propagation Panel Symposium on Digital Communications Systems. Available at https://apps.dtic.mil/sti/pdfs/ADA310824.pdf#page=135

Results: Time series from N6GN



What to expect: Path, Equipment, Length: Quick Assessment at 14 MHz



Conclusions

- FST4W on the HF bands:
  - Is entirely practical with readily available equipment.
  - The -120 variant works over global paths.
  - Spurs attention to technical attention and innovation on drift / spread.
  - Measures spectral width giving another view of propagation variations, independent of SNR.
  - Deserves more attention from the amateur community and maybe professional ionospheric scientists.

Further Work

- Two improvements to KiwiSDR frequency stability and absolute accuracy have been made – reassess spread.
- It would be terrific if the QRP Labs $69 QDX transceiver had lower spectral spread on transmit.
- Better understand FST4W SNR algorithm – why 12.5 $\log_{10}$ term?
- Endless questions on spectral width and propagation, e.g. paths to KiwiSDRs at Inuvik and Eureka at and inside the Auroral Oval; is the 14 MHz path from Sonoma County to KFS, Half Moon Bay via ocean surface backscatter? etc.