HF Ionospheric Surveillance Radars and Associated Transmissions

- CODAR
- SuperDARN
- DISS
- VIPIR
- ROTHR and associated ionosondes

David L. Wilson

CODAR

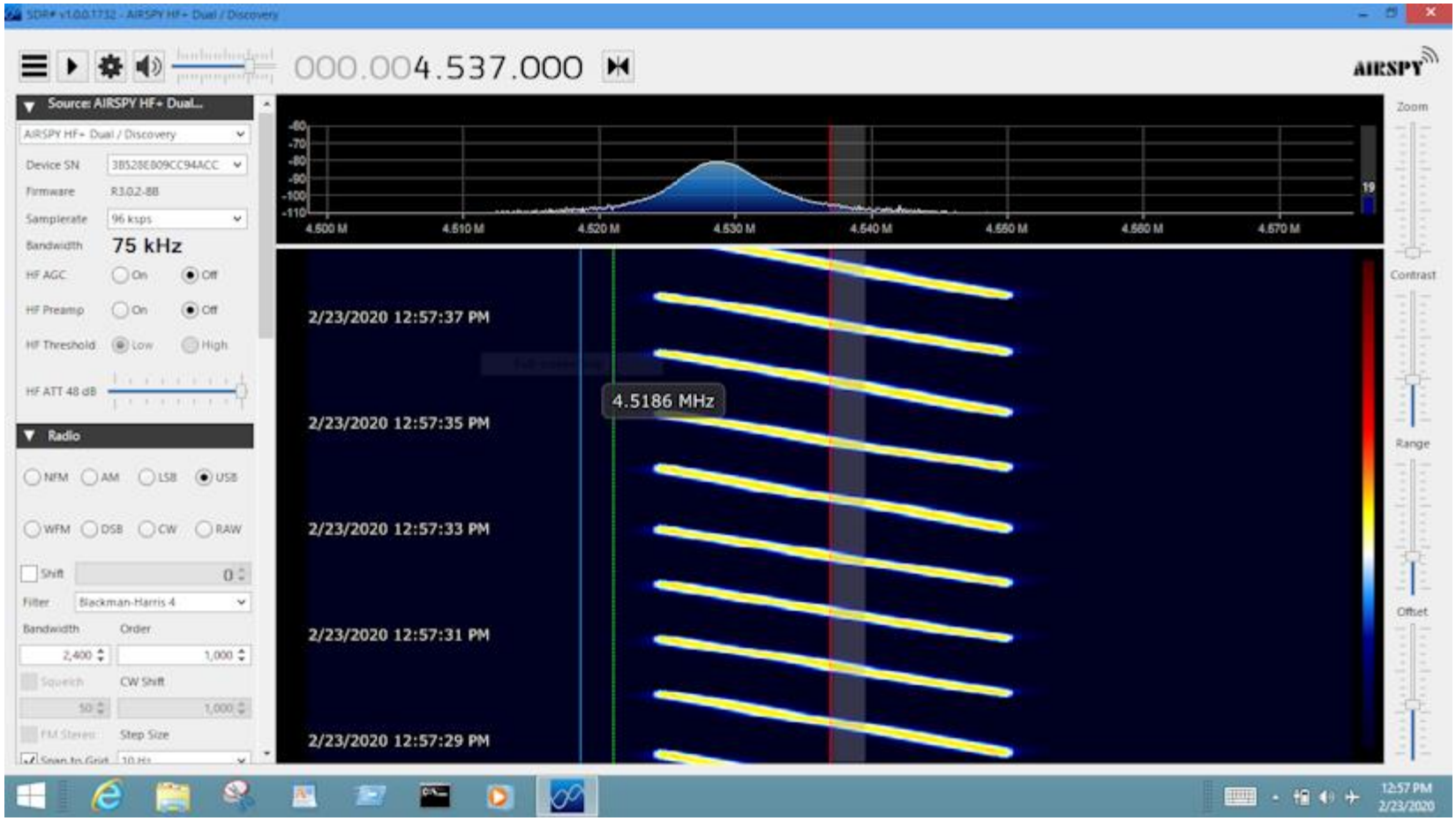
(Coastal Ocean Dynamics Applications Radar)

- Measures ocean currents and wave parameters
- Usually operated by universities
- Bi-static (separate receive and transmit)
- Separate locations operate within 4438-4488 KHz, 5250-5275 kHz, 9305-9355 kHz, 13450-13550 kHz, 16100-16200 kHz, 24450-24650 kHz, 26200-26420 kHz, 39.0-40.0 MHz, and 42.0-42.5 MHz - with specific allocations depending on ITU region.
- Roughly 50 W and easily heard in 4.5-5.6 MHz

(Photographs by David L. Wilson)

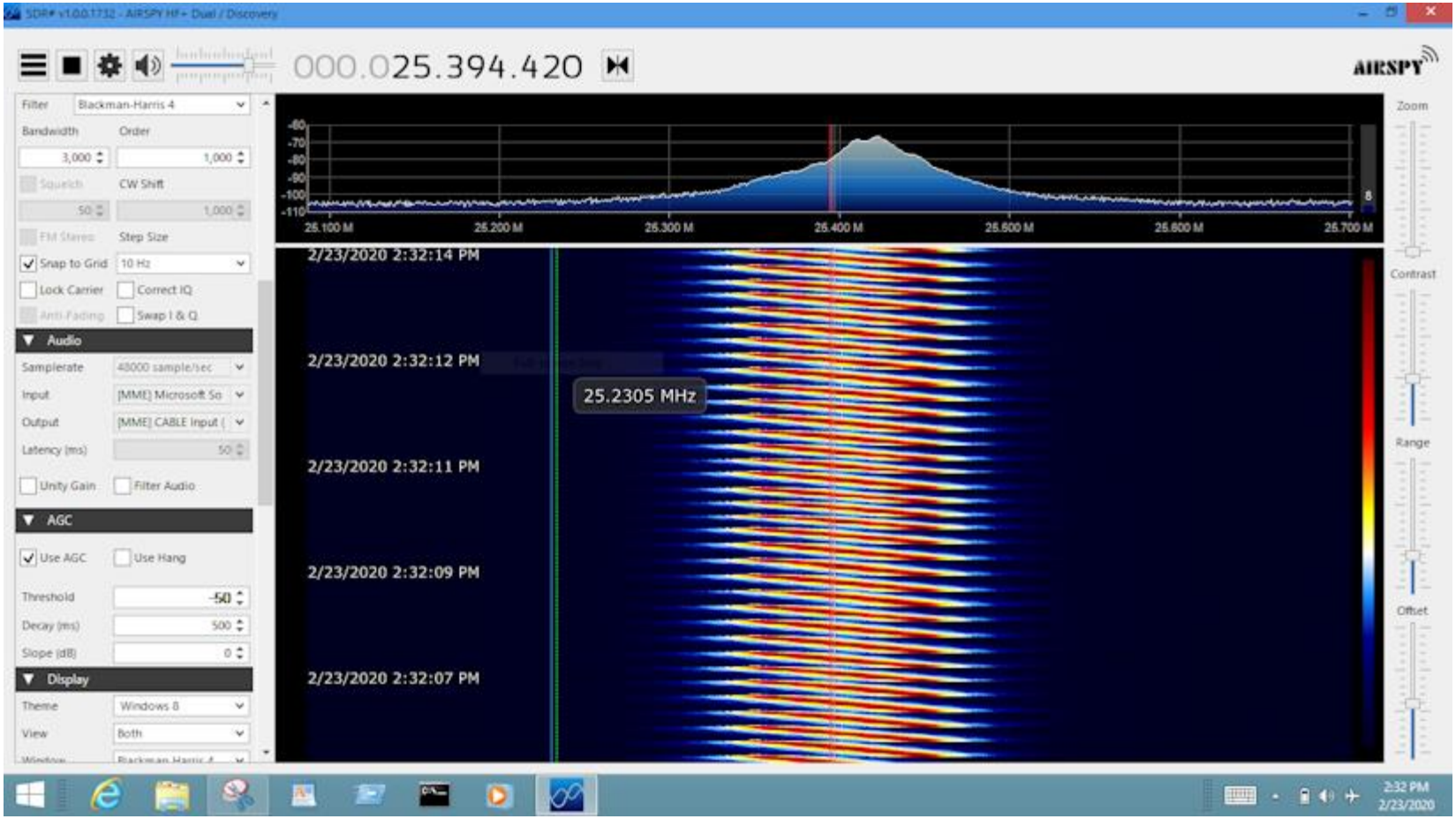
“LISL” Little Island Park-Virginia Beach, VA (4537 kHz, 25.73 kHz BW, 1 Hz Pulse Repetition Rate)

(In Virginia, Old Dominion University operates 5 locations.)



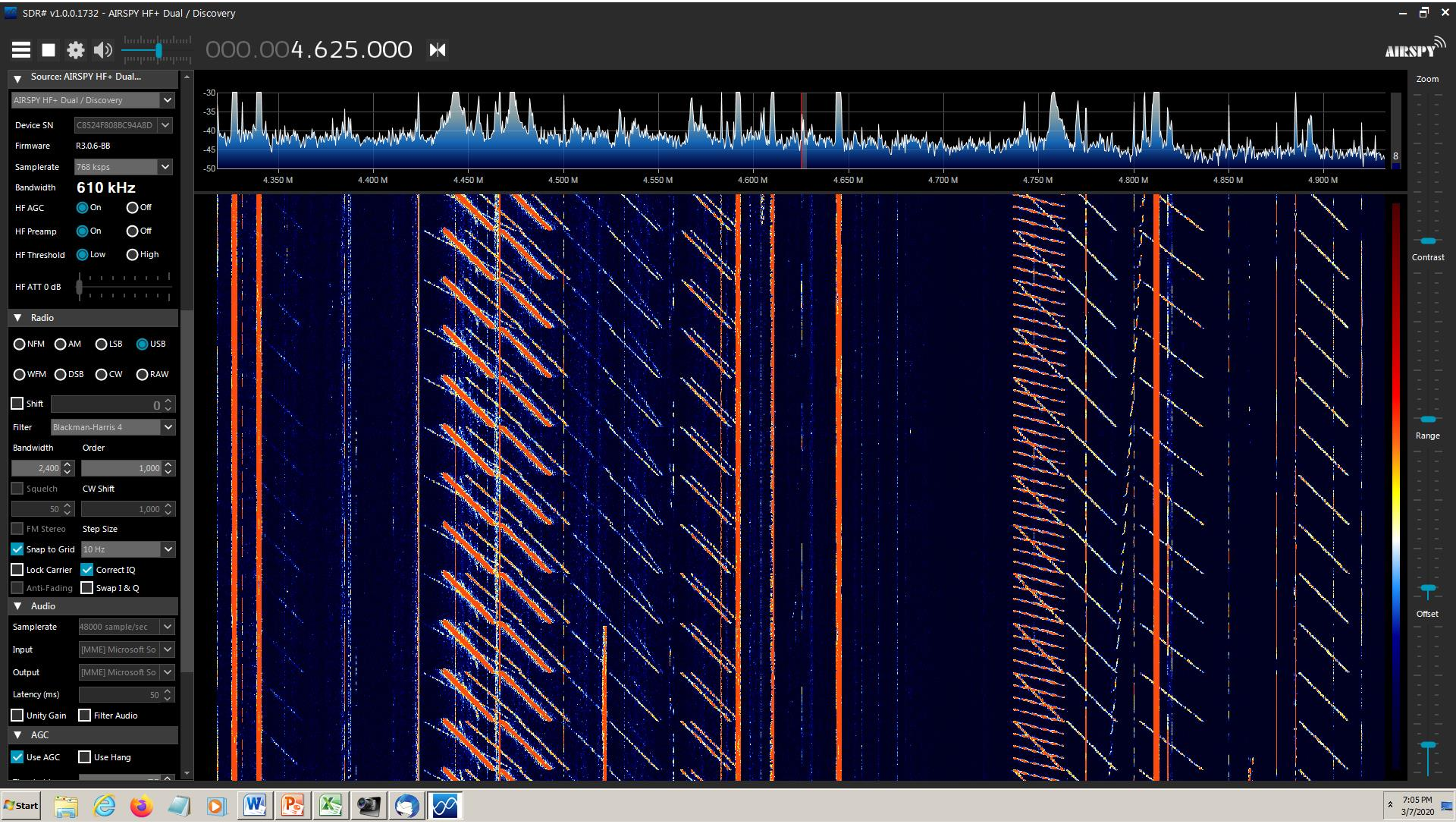
(sample lisl.wav)

“VIEW” Ocean View Park-Norfolk, VA (25.400 MHz, 101.10 kHz BW, 4 Hz Pulse Repetition Rate)



(sample oview.wav)

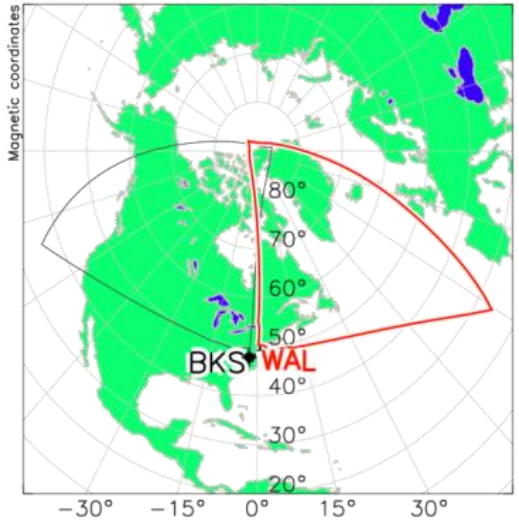
There are many CODAR stations along the US coasts in the 4 MHz band



SuperDARN

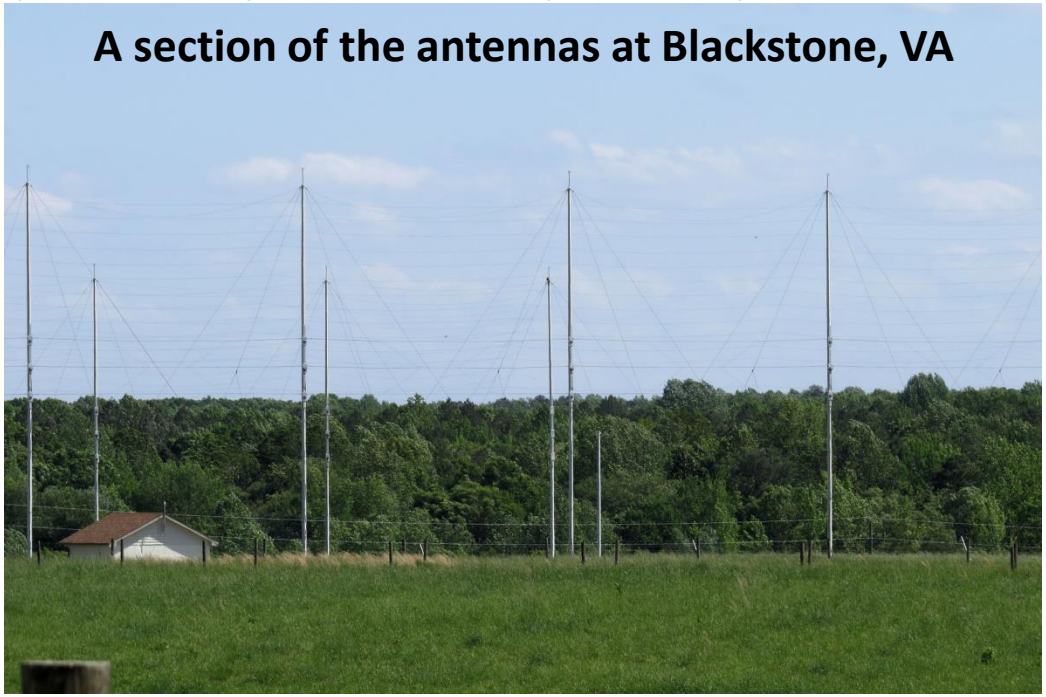
- "SuperDARN" stands for "Super Dual Auroral Radar Network".
- SuperDARN is used to study plasma convection in the upper atmosphere.
- The radars use frequencies is 8-20 MHz with directional transmissions.
- SuperDARNs "BKS" is at Blackstone operated by Virginia Tech and "WAL" is at NASA Wallops Mainland (Temperanceville), VA operated by JHU APL.
- There are roughly 30 SuperDARN sites throughout the world. There are SuperDARN transmitters in Alaska, Kansas, Oregon, and Canada.
- Transmissions consists of a periodically transmitted pulse sequence.

Coverage of BKS and WAL



(Source: http://vt.superdarn.org/tiki-index.php?page=Wallops+Island+Info)

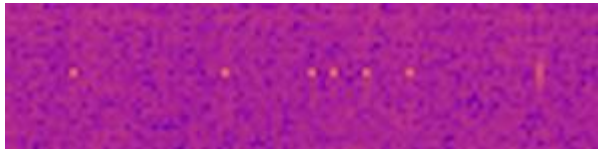
A section of the antennas at Blackstone, VA



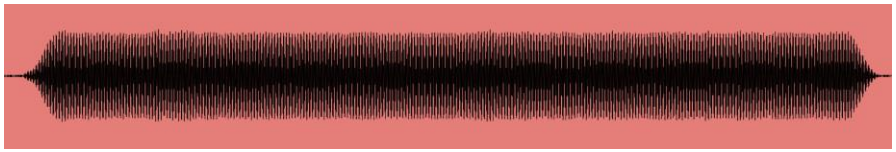
(Photograph by David L. Wilson)

Example of Blackstone ("BKS") SuperDARN Pulse Sequence

Spectrogram (time vs. frequency) showing a pulse sequence of eight 300 us pulses (the "blurred" pulse being actually 2 pulses) on 14.5 MHz



One of the 300 us (microsecond) pulses



Successive transmission of two of the 8-pulse sequences (T = 1.5 ms) on 14.5 MHz

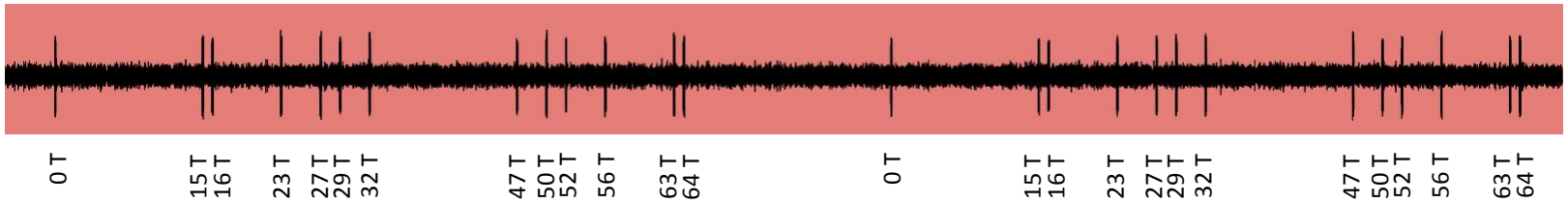
[0, 14, 22, 24, 27, 31, 42, 43] gives all lag times from 1 to 43 except 6, 23, 25, 26, 30 , and 32-41.
This sequence "reversed" is [0, 1, 12, 16, 19, 21, 29, 43]. Both sequences are know as the "8-pulse katscan 1500".
Often about 30 of these sequences are transmitted in repetition before shifting to another frequency.

(sample SuperDARN BLK.wav)

(Plots produced with a HackRF One receiver using Universal Radio Hacker software.)

Example of Wallops ("WAL") SuperDARN Pulse Sequence

Successive transmission of two of the 13-pulse sequences (T = 2.4 ms) on 11.0 MHz



This sequence [0, 15, 16, 23, 27, 29, 32, 47, 50, 52, 56, 63, 64] is different than the sequence used by Blackstone above. It can be thought of as concatenating sequences [0,15], [0, 1, 8, 12, 14, 17], [0, 15], and [0, 3, 5, 9, 16, 17], where the last sequence [0, 3, 5, 9, 16, 17] is the "reverse" of the earlier [0, 1, 8, 12, 14, 17].

(sample SuperDarn WAL.wav)

Wallops SuperDARN antenna (at Wallops Mainland near Temperanceville)
16 transmitters with an average power of 18 W

(Plots produced with a HackRF One receiver using Universal Radio Hacker software. Photograph by David L. Wilson)

Ionospheric Sounders at Wallops Main Base

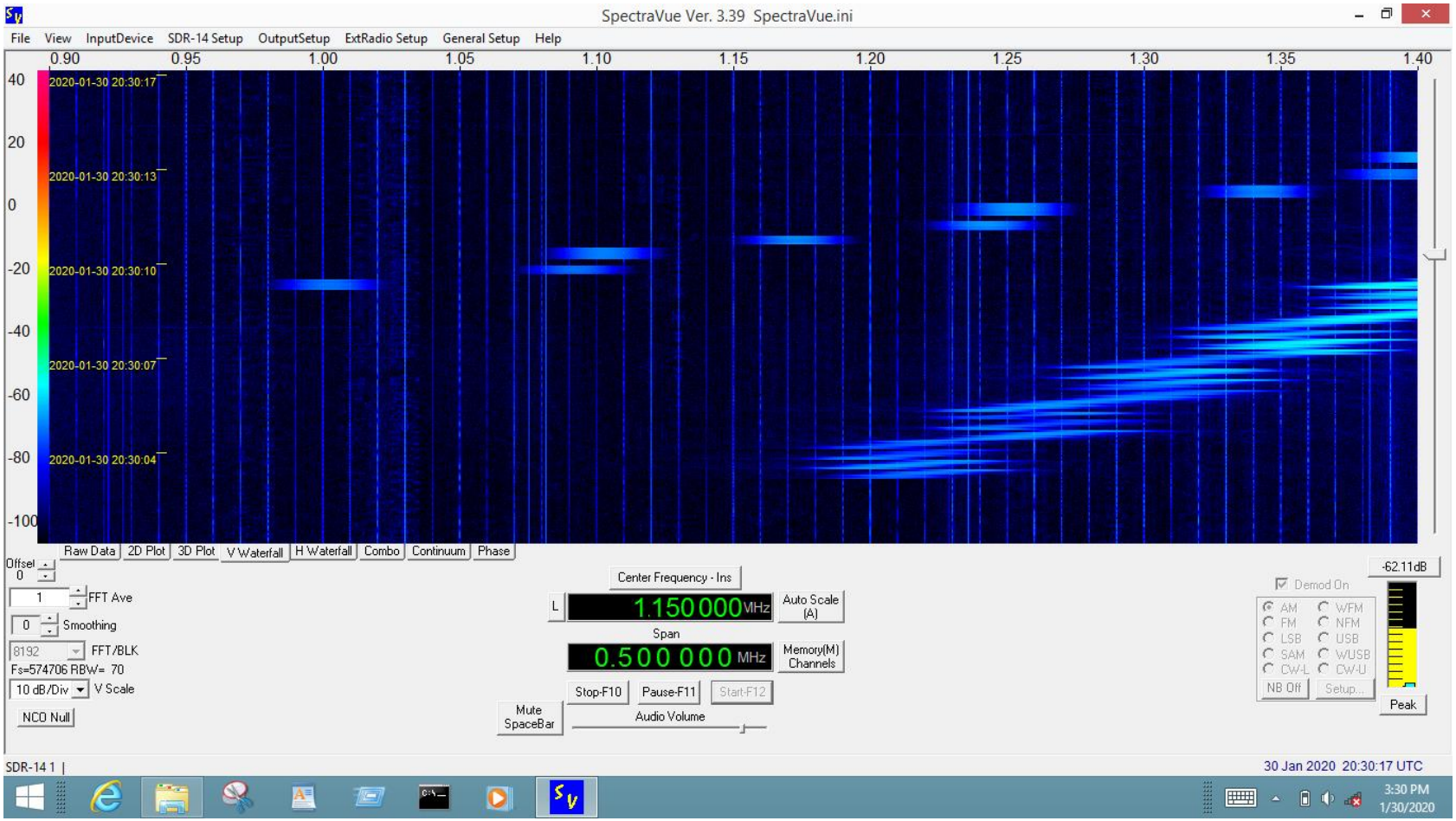
VIPIR (“WI937”)

- **V**ertical **I**ncidence **P**ulsed **I**onosphere **R**adar
- NOAA
- Sweeps every 2 minutes starting near 1200 kHz
- Made by Scion Associates Inc.
- Pulse-to-pulse time of 10 ms
- Pulse groups of 8 pulses separated by 10 ms in frequency blocks of 16 pulse groups in 4 frequency in 4 time windows

DISS (“WP937”)

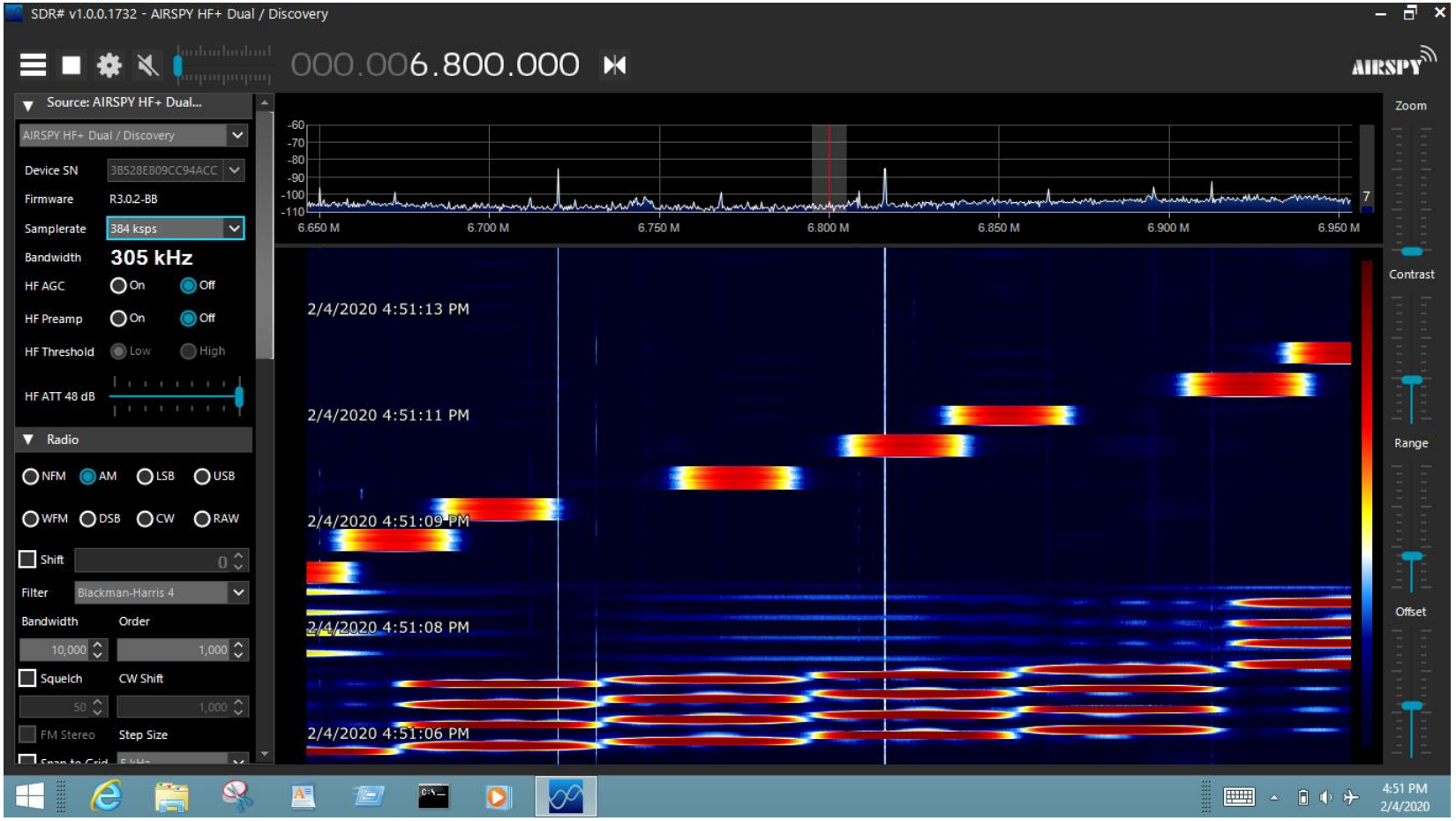
- **D**igital **I**onospheric **S**ounder **S**ystem
- USAF
- Sweeps every 5 minutes starting near 1000 kHz
- Made by LDI (Lowell Digisonde Intl.)
- Pulse-to-pulse time of 5 ms
- 67 pulse groups with 5 ms between pulses (330 ms total time) and 170 ms between groups

DISS (every 5 minutes) starts its logarithmic sweep near 1.0 MHz
and
VIPIR (every 2 minutes) starts its logarithmic sweep near 1.2 MHz.



(SDR-14 SpectraVue software, 9:1 transformer, and 15 ft wire antenna)

Both DISS and VIPIR logarithmically sweep upward in frequency.

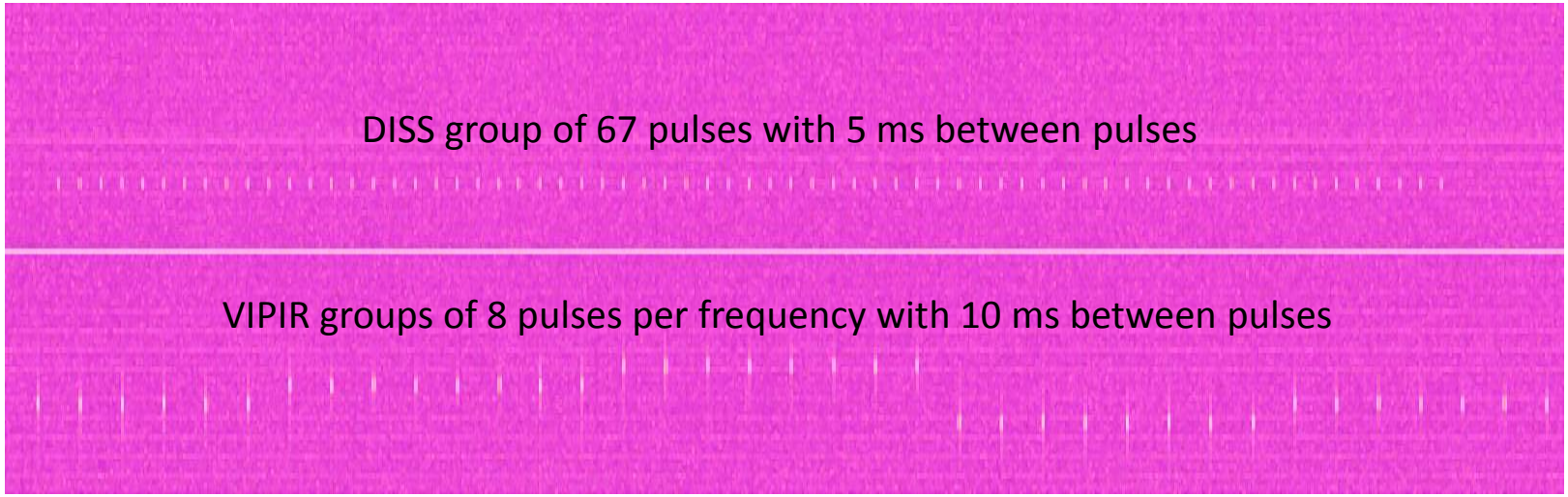


(Airspy HF+ Discovery using SDRSharp software, 9:1 transformer, and 15 ft wire antenna)

(sample Wallops DISS 5414.wav)

(sample Wallops VIPIR 5414.wav)

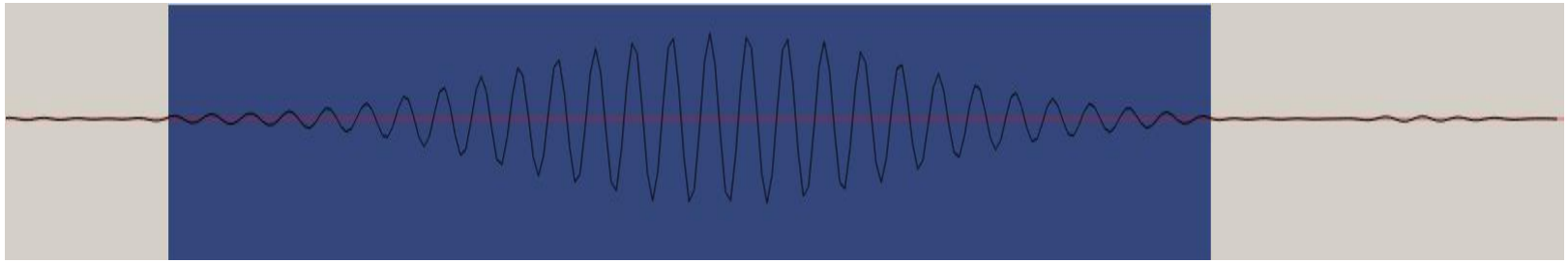
DISS and VIPIR pulse groups



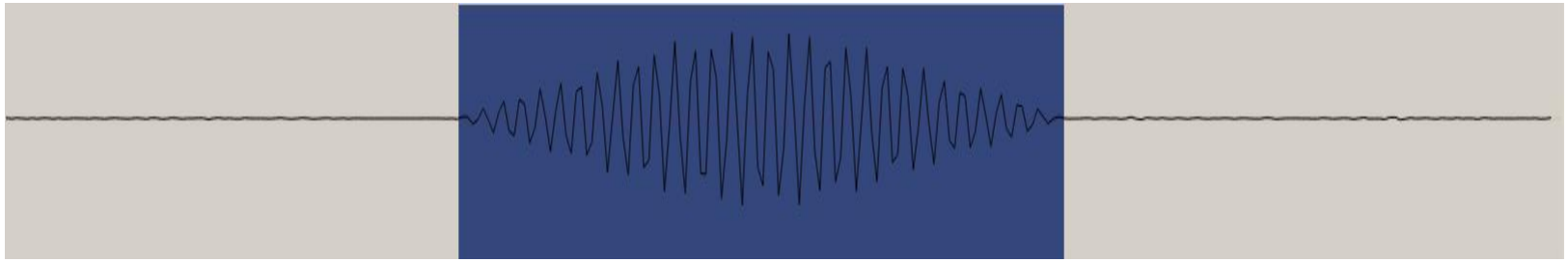
(Plot produced with a HackRF One receiver using Universal Radio Hacker software. 9:1 transformer with 15 foot wire antenna)

DISS and VIPIR single pulses

DISS (blue shade indicates 100 us)

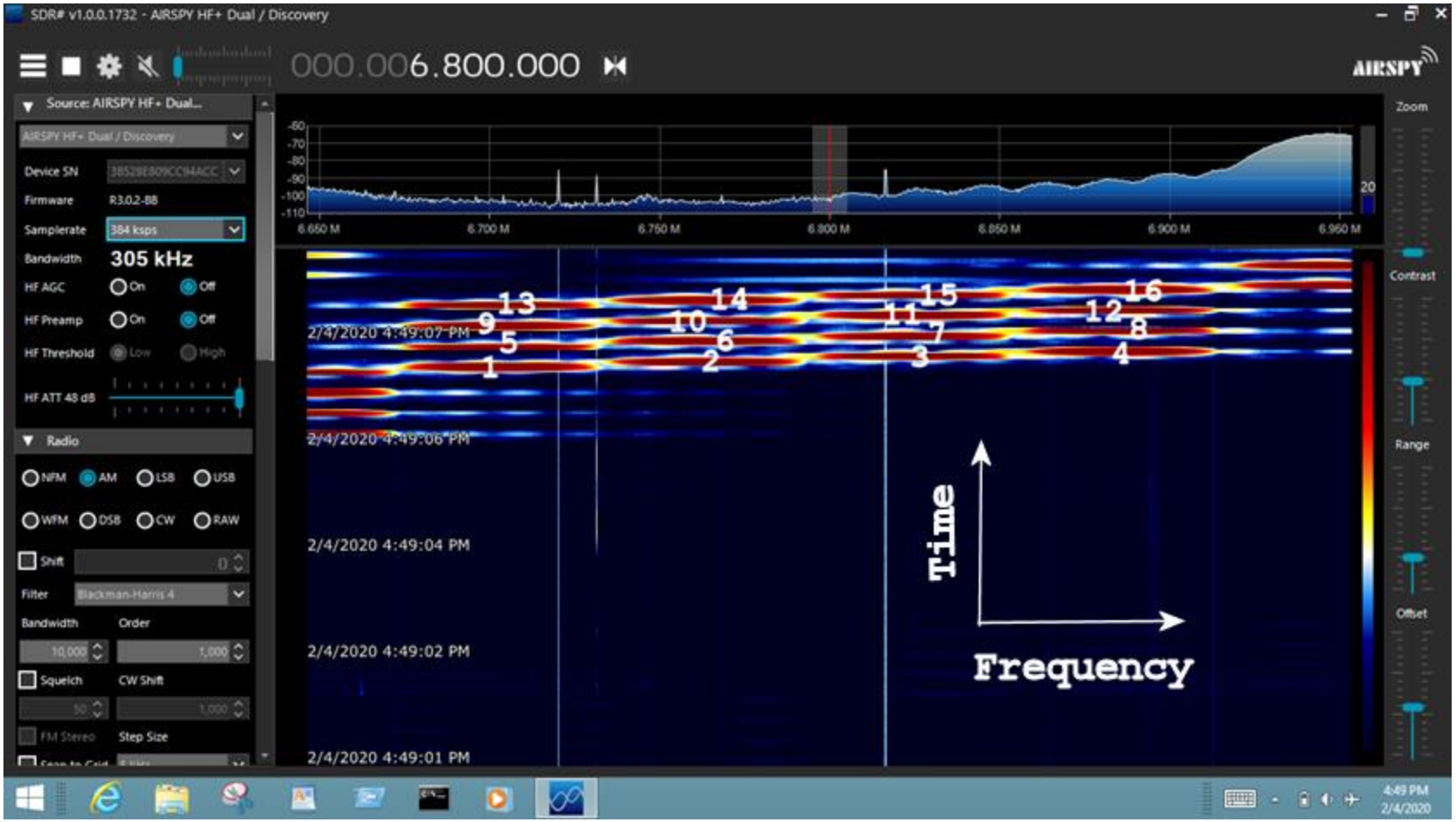


VIPIR (blue shade indicates 58 us)



(Plot produced with a HackRF One receiver using Universal Radio Hacker software. 9:1 transformer with 15 foot wire antenna)

Order of VIPIR transmission of pulse groups.



(Airspy HF+ Discovery using SDRSharp software, 9:1 transformer, and 15 ft wire antenna)

Wallops transmitter VIPR Apex-down Zig-Zag Log Periodic Antenna (ZZLPA)

(Photograph by David L. Wilson)

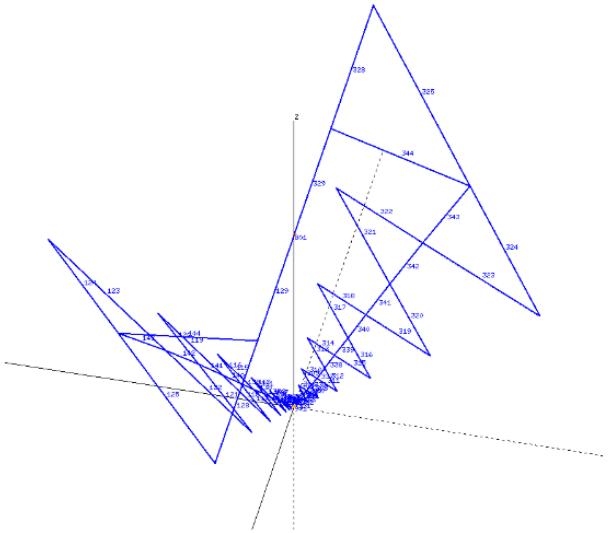


Figure from
"Transmit Antenna for Ionospheric Sounding Applications",
Terence W. Bullett and Robert J. Redmon

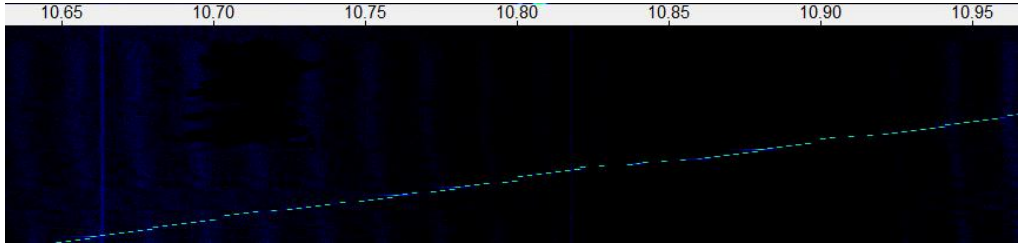
One of the Wallops VIPIR receive antennas

(Photograph by David L. Wilson)

U.S. Navy ROTHR
(Re-locatable Over-The-Horizon Radar)

(Map source:
http://www.iarums-r1.org/iarums/radar-2013.pdf)

- Designated AN/TPS-71
- Operations support and maintenance by Raytheon Co.
- Maritime surveillance and drug interdiction
- Bistatic (transmitter and receiver at different locations)
- Uses frequencies from 5 to 28 MHz
- Three locations:
  ROTHR-VA New Kent transmit and Chesapeake receive
  ROTHR-TX Premont transmit and Freer receive
  ROTHR-PR Playa Grande (Vieques) transmit
  and Ft. Allen (Ponce) receive
- Two HF ionosondes are present at each transmit site



One of the two ionosondes at New Kent.
This site is near White Oak Landing on the Pamunkey River.

(SDR-14 and SpectraVue software, 9:1 transformer and 15 ft wire antenna)

(Seal source:
http://www.mobileradar.org/Documents/ROTHR.pdf)

U.S. Navy ROTHR Transmit site-New Kent, VA

Observed New Kent Pulses and Sub-pulses

Sub-pulse (chirp) Sweep time [ms]	Repetitions of sub-pulse	Total time [ms]	Chirp rate [kHz/s]	Frequency Sweep ("Bandwidth") [kHz]
24.0	64	1536.0	8/24=333.333	8
24.0	128	3072.0	8/24=333.333	8
32.0	32	1024.0	6/24=250.000	8
32.0	64	2048.0	6/24=250.000	8
38.4	32	1228.8	5/24=208.333	8
38.4	64	2457.6	5/24=208.333	8
48.0	32	1536.0	4/24=166.667	8
48.0	64	3072.0	4/24=166.667	8
(rare) 192.0	64	12288.0	6/24=250.000	48

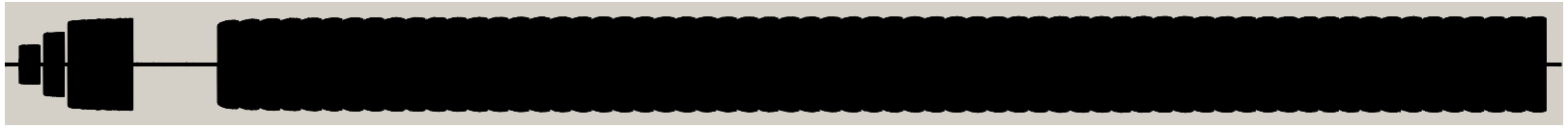
Note: 38.4 ms corresponds to the average of the frequencies for 32.0 ms and 48.0 ms: 1/((1/32+1/48)/2)=38.4.

Example of Sub-pulses (Chirps)

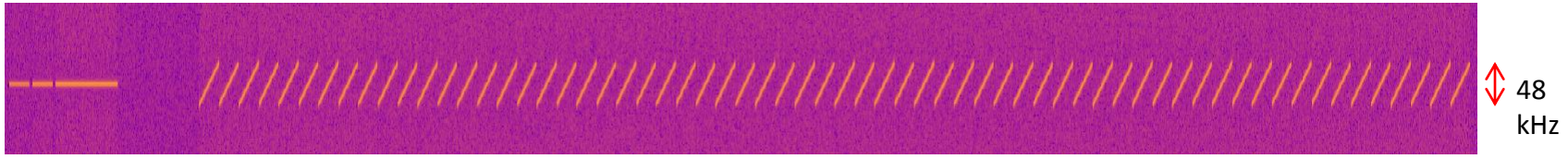
in a 64 x 192 ms = 12.288 s pulse

after 192 ms carrier (33 ms pause) 192 ms carrier (33 ms pause) 600 ms carrier (785 ms pause)

Analogue

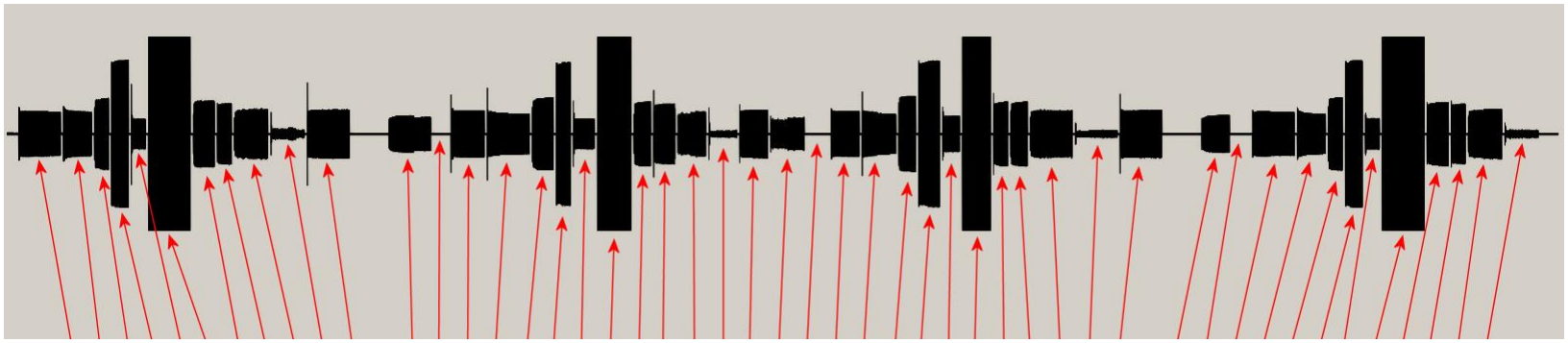


Spectrogram



All the above sub-pulses (chirps) linearly sweep upwards in frequency at 1/4 kHz/ms = 250 Hz/s.
For these 192 ms sub-pulses, this means each linearly slides upwards in frequency 192/4= 48 kHz.

Sample Of New Kent, VA ROTHR Pulses Merged from Different Frequencies to Same Time Line



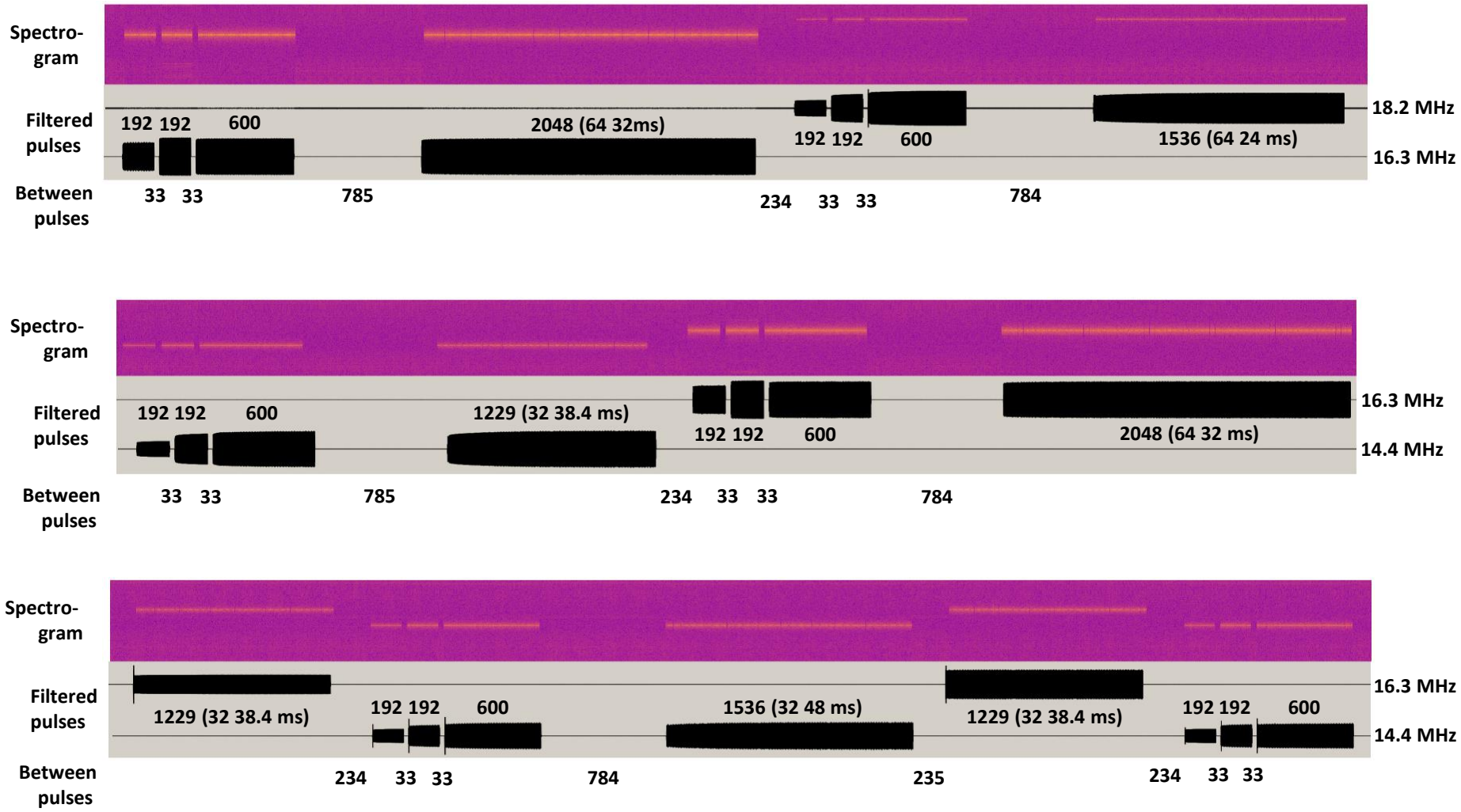
Frequency [MHz]	Sub-pulse [ms]	Sub-pulse repeats	Pulse [ms]	(Post) Delay [ms]
18.42	24.0	128	3072.0	234.0
18.42	32.0	64	2048.0	235.0
18.36	32.0	32	1024.0	234.0
18.02	38.4	32	1228.8	234.2
18.36	32.0	32	1024.0	235.0
18.42	24.0	128	3072.0	234.0
18.36	24.0	64	1536.0	234.0
18.36	32.0	32	1024.0	235.0
18.13	38.4	64	2457.6	234.4
18.02	38.4	64	2457.6	234.4
18.13	24.0	128	3072.0	
			2935.0	
18.13	24.0	128	3072.0	234.0
	32.0	32	1024.0	234.0
18.45	38.4	64	2457.6	234.4
18.45	24.0	128	3072.0	235.0
18.36	24.0	64	1536.0	234.0
18.02	32.0	32	1024.0	235.0
18.36	24.0	64	1536.0	234.0
18.45	38.4	64	2457.6	234.4
18.36	38.4	32	1228.8	234.2
18.36	24.0	64	1536.0	235.0
18.13	32.0	64	2048.0	234.0
18.02	32.0	64	2048.0	234.0
18.13	32.0	64	2048.0	235.0
18.13	38.4	64	2457.6	234.4
	24.0	64	1536.0	234.0
18.45	32.0	64	2048.0	235.0
18.45	38.4	64	2457.6	234.4
18.33	38.4	32	1228.8	234.2
18.02	24.0	64	1536.0	234.0
18.33	38.4	32	1228.8	234.2
18.45	32.0	64	2048.0	235.0
18.33	32.0	32	1024.0	234.0
18.33	38.4	32	1228.8	234.2
18.13	24.0	128	3072.0	235.0
18.02	24.0	128	3072.0	234.0
18.13	24.0	128	3072.0	
			2935.0	235.0
18.13	32.0	64	2048.0	234.2
			1228.8	234.0
18.43	24.0	128	3072.0	234.0
18.43	32.0	64	2048.0	234.0
18.36	32.0	32	1024.0	235.0
18.02	38.4	32	1228.8	234.2
18.36	32.0	32	1024.0	234.0
18.43	24.0	128	3072.0	235.0
18.36	24.0	64	1536.0	234.0
18.36	32.0	32	1024.0	235.0
18.13	38.4	64	2457.6	234.4
18.02	38.4	64	2457.6	

Note: Some pulses occurred outside the received bandwidth so some measurements were not possible.

(Plot produced by HackRF One receiver using Universal Radio Hacker software, 9:1 transformer and 15 ft wire antenna)

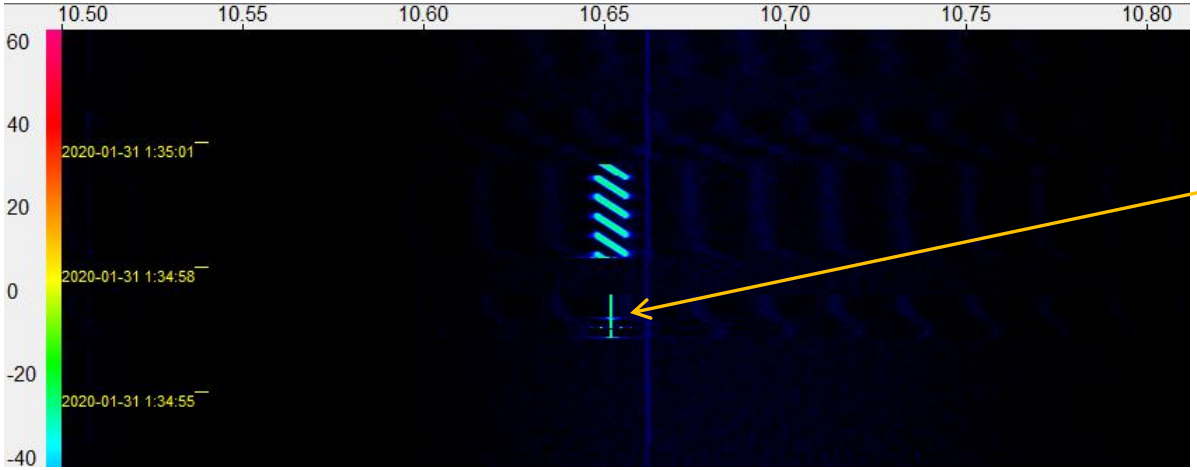
More Samples Of Observed New Kent, VA ROTHR Pulses

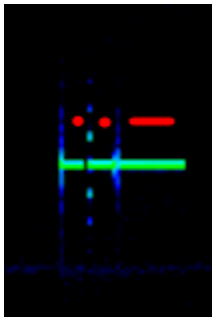
Time intervals are in milliseconds [ms]. Spectrogram plots are time vs. frequency.



(HackRF One receiver using Universal Radio Hacker software, 9:1 transformer and 15 ft wire antenna)

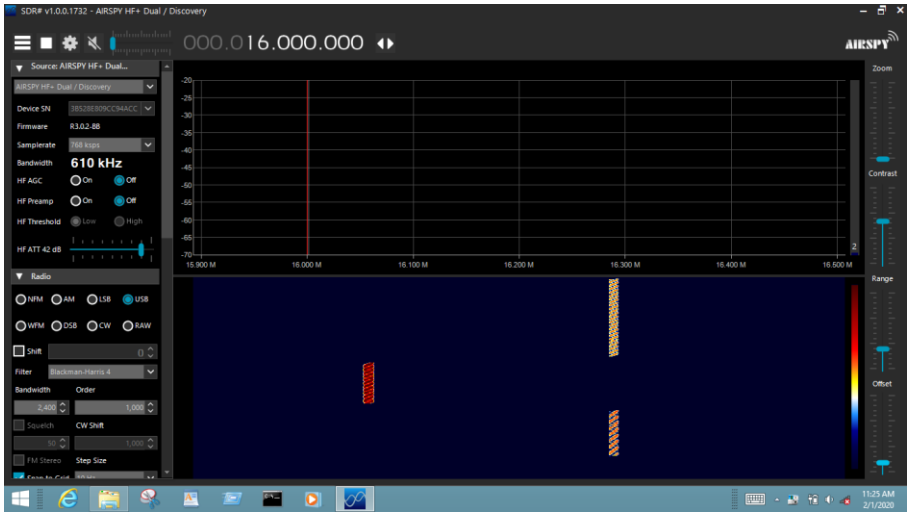
Select Samples Of Observed New Kent, VA ROTHR Pulses

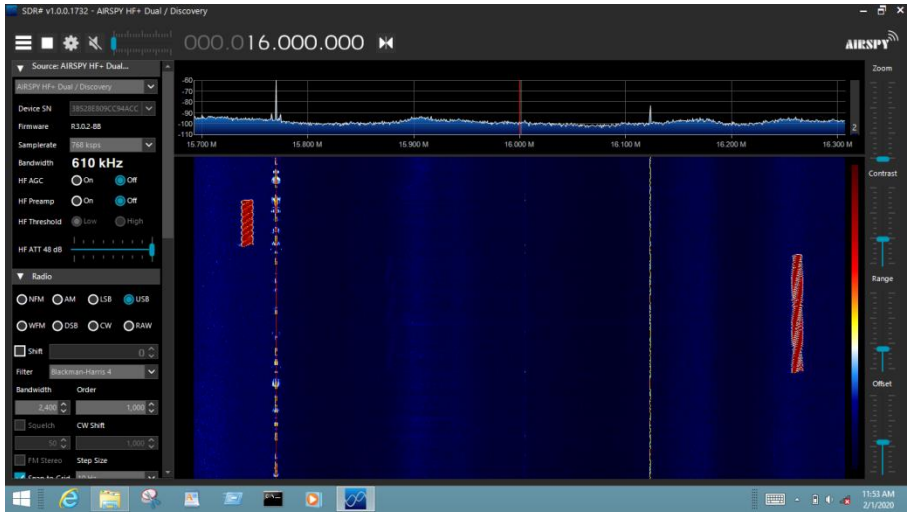




(SDR-14 using SpectraVue software)

The ROTHR sometimes sends what sounds like a cw "U" (• • –) before a pulse. "•" are 192 ms and "–" are 600 ms.



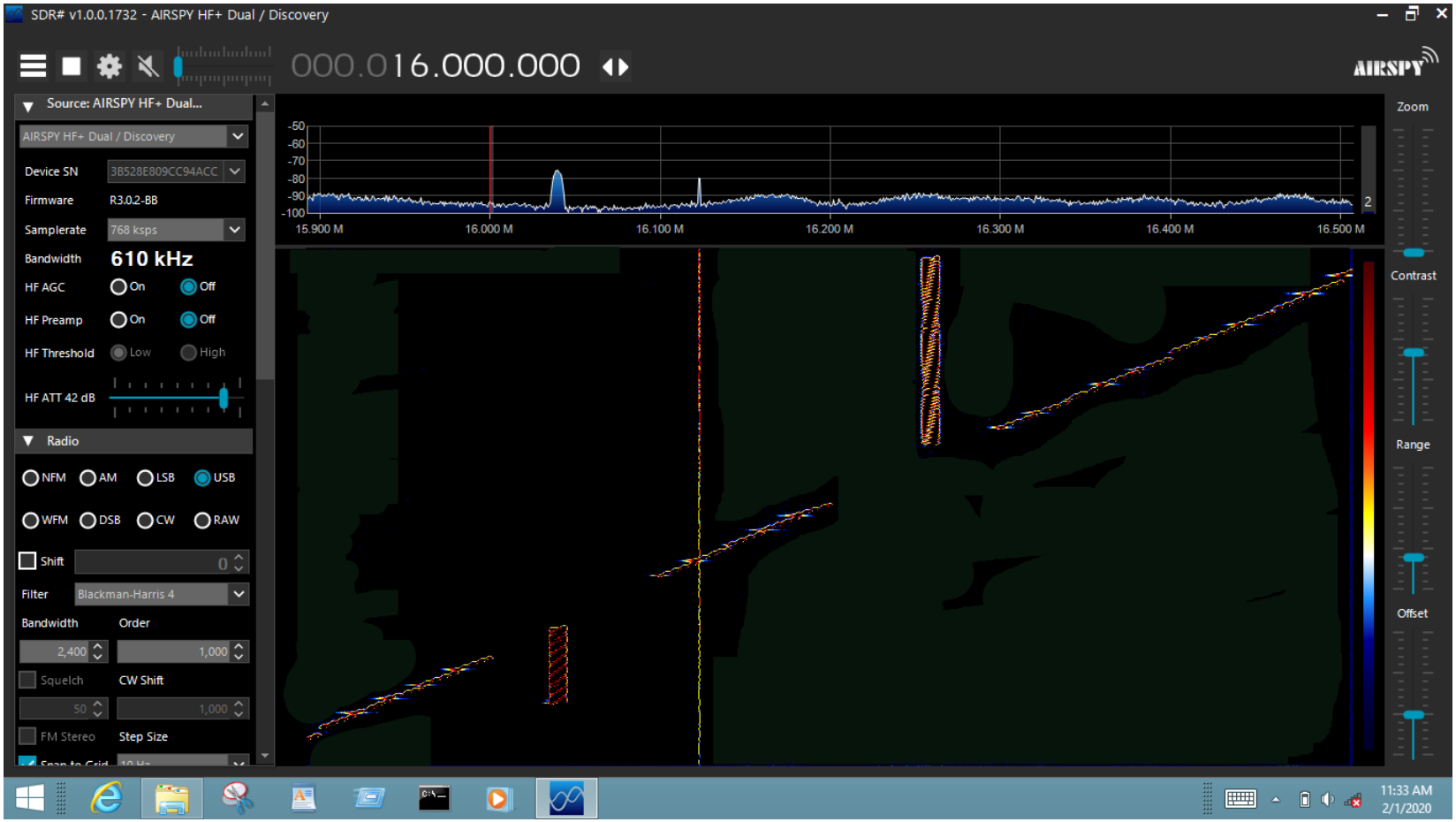


(AirSpy HF+ discovery using SDRSharp software, 9:1 transformer and 15 ft wire antenna)

(New Kent ionsondes and ROTHR: Sample New Kent 10250.wav)

Note: Aliasing often gives false impressions of the FMOP (Frequency Modulation On Pulse).

Select Samples Of Observed New Kent, VA ROTHR Pulses

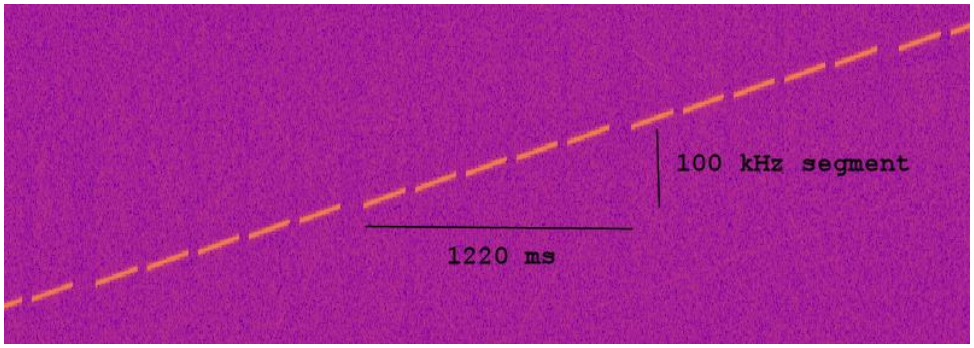


One of the New Kent ionosondes skipping over active New Kent ROTHR frequencies

(AirSpy HF+ discovery using SDRSharp software, 9:1 transformer and 15 ft wire antenna)

Two Ionosondes at each ROTHR

- Both ionsondes start simultaneously every 12 minutes.
- The 2-20 MHz ionosonde sweeps upwards at 10 s/MHz.
- The 5-28 MHz ionosonde actually sweeps with 100 kHz segments having 20 kHz sub-segments with sweeps at 10 s/MHz (100 Hz/ms). The overall effect is 12.2 s/MHz except when due to exceptions (next bullet).
- The 5-28 MHz ionosonde skips over frequencies for WWV, search and rescue, and other frequencies. There are transmission delays at 7.900, 11.900, and 17.800 MHz.
- The next couple slides show more finer transmission details of the 5-28 MHz ionosonde.

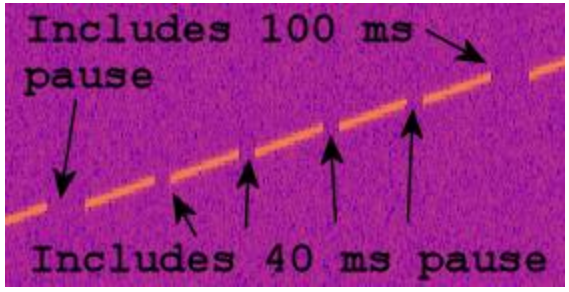


ROTHR (New Kent) 5-28 MHz Ionosonde Analysis (1)

Normal transmission pattern

- Pause 100 ms
- Pause 192 – T_1 ms (so total pause is 292 – T_1 ms)
- XX.X00 MHz Sweep T_1 ms upwards in frequency at 100 Hz/ms
- Pause 40 ms
- Pause 192 – T_2 ms (so total pause is 232 – T_2 ms)
- XX.X20 MHz Sweep T_2 ms upwards in frequency at 100 Hz/ms
- Pause 40 ms
- Pause 192 – T_3 ms (so total pause is 232 – T_3 ms)
- XX.X40 MHz Sweep T_3 ms upwards in frequency at 100 Hz/ms
- Pause 40 ms
- Pause 192 – T_4 ms (so total pause is 232 – T_4 ms)
- XX.X60 MHz Sweep T_4 ms upwards in frequency at 100 Hz/ms
- Pause 40 ms
- Pause 192 – T_5 ms (so total pause is 232 – T_5 ms)
- XX.X80 MHz Sweep T_5 ms upwards in frequency at 100 Hz/ms

Total time of the above is 1220 ms. (Although T_1, T_2, T_3, T_4, and T_5 vary between 187 and 192 ms.) Pattern continues over next 100 kHz with same or different pulse times T_1, T_2, T_3, T_4, and T_5 (the pulse time pulse pattern repeats for a while then changes).



Exceptions

Skips:

5.000 – 5.020 MHz (5.000 WWV)
5.660 – 5.700 MHz (5.680 Search & Rescue)
6.200 – 6.300 MHz
8.340 – 8.380 MHz
9.980 – 10.020 MHz (10.000 WWV)
13.340 – 13.420 MHz
14.980 – 15.020 MHz (15.000 WWV)
19.980 – 20.020 MHz (20.000 WWV)
21.840 – 21.880 MHz
24.980 – 25.020 MHz (25.000 WWV)
25.540 – 25.700 MHz (25.550-25.670 Radio Astronomy)
27980 – 28.000 MHz

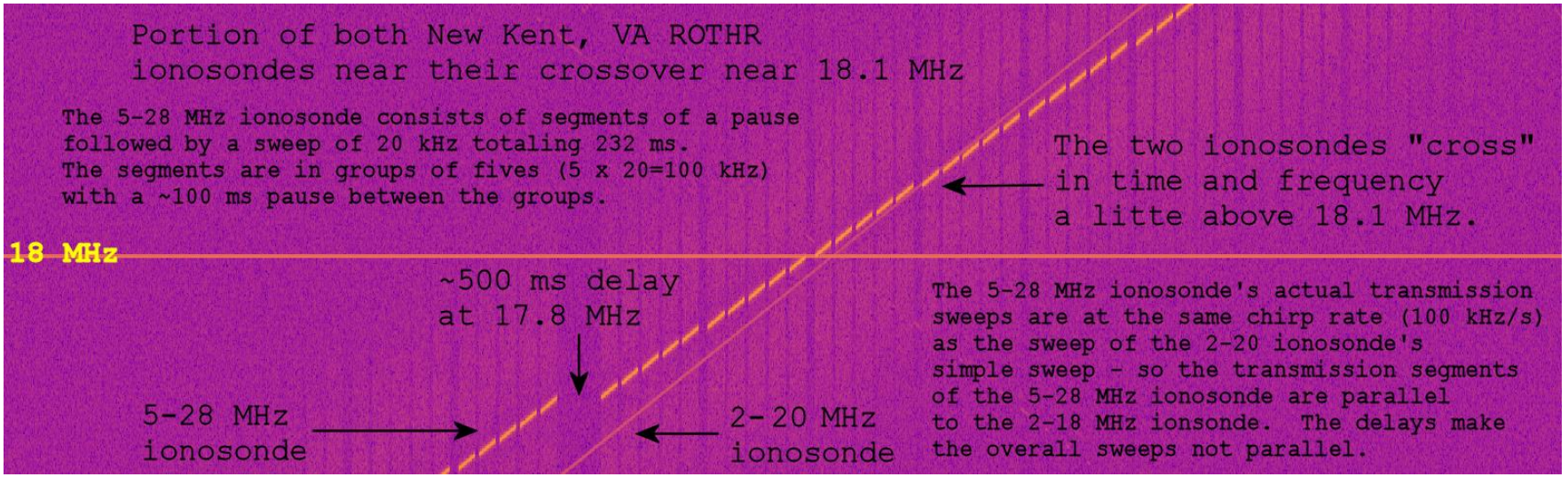
Extra 500 ms delays at:

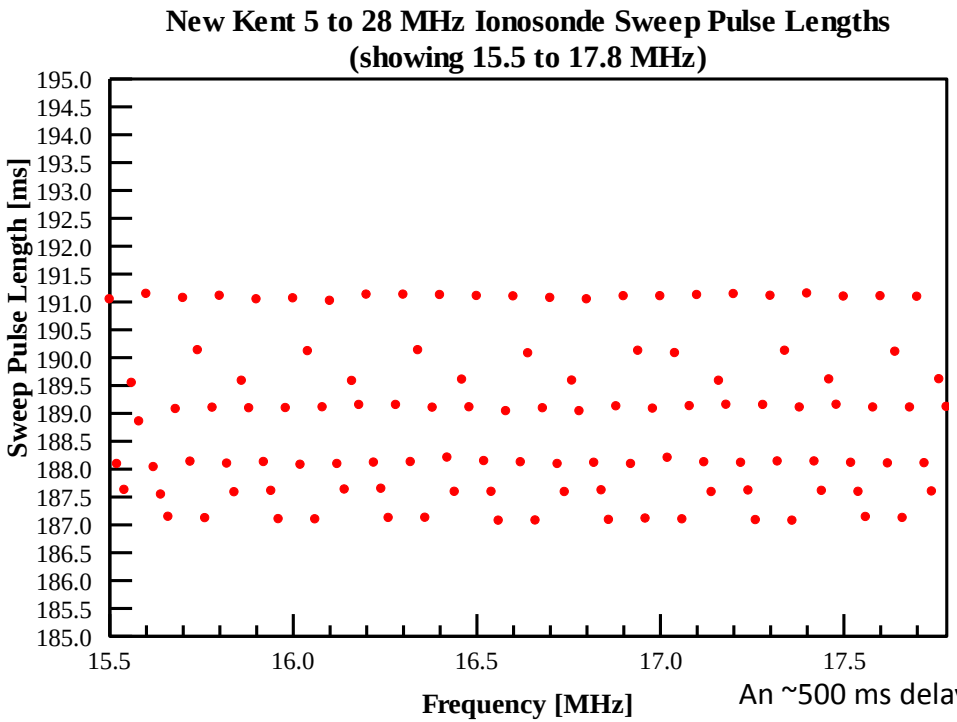
7.900 MHz
11.900 MHz

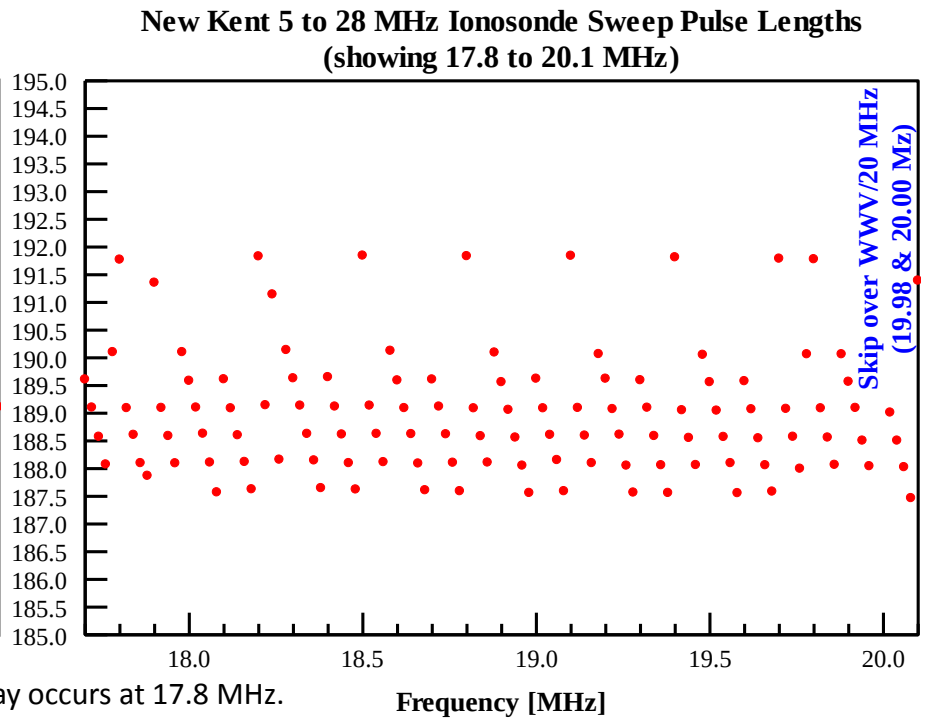
and a 501 ms delay at:

17.800 MHz

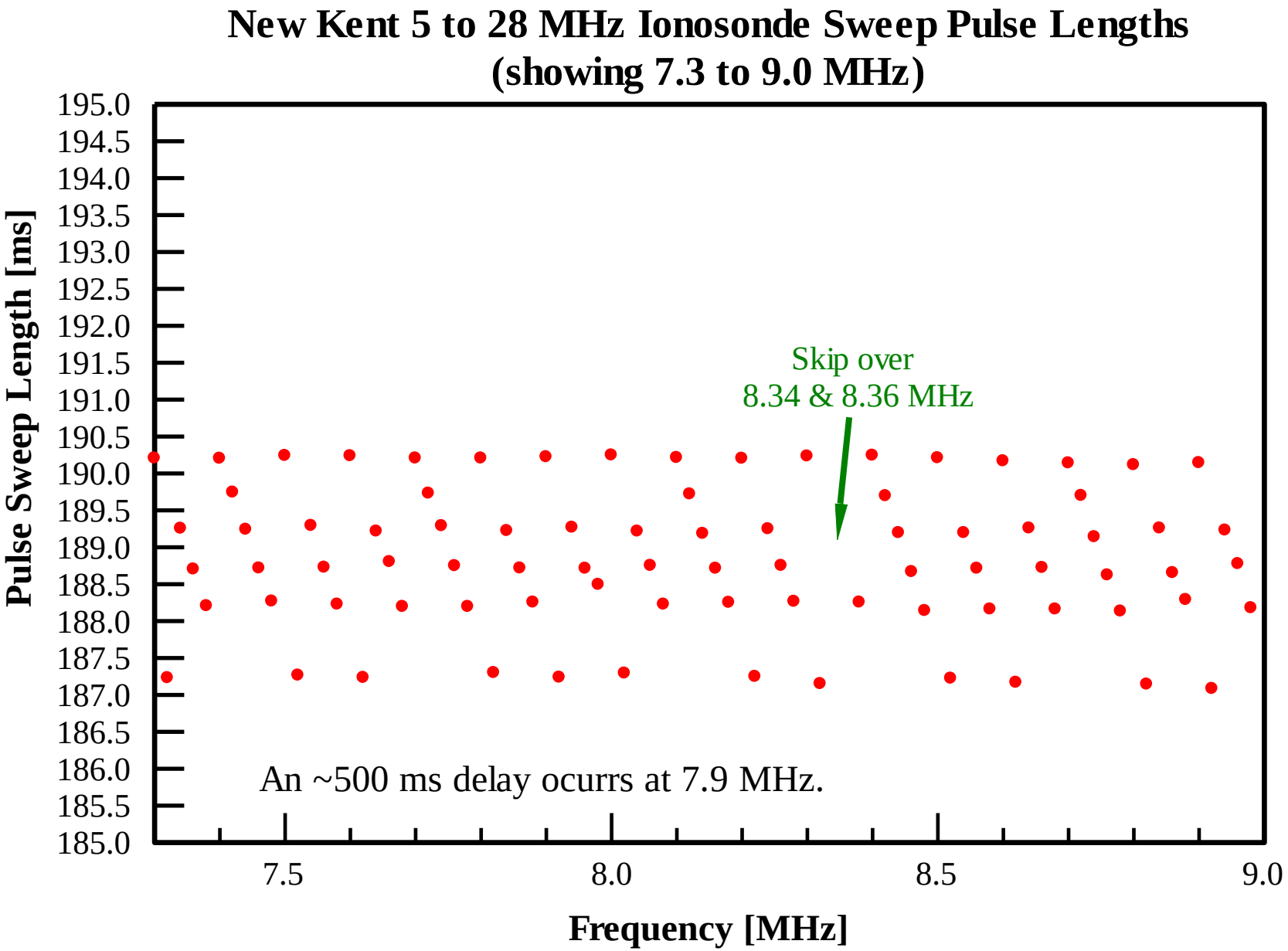
ROTHR (New Kent) 5-28 MHz Ionosonde Analysis (2)







An ~500 ms delay occurs at 17.8 MHz.


New Kent 5 to 28 MHz Ionosonde Sweep Pulse Lengths
(showing 7.3 to 9.0 MHz)
Pulse Sweep Length [ms]
195.0
194.5
194.0
193.5
193.0
192.5
192.0
191.5
191.0
190.5
190.0
189.5
189.0
188.5
188.0
187.5
187.0
186.5
186.0
185.5
185.0
Skip over
8.34 & 8.36 MHz
An ~500 ms delay ocurrs at 7.9 MHz.
7.5
8.0
8.5
9.0
Frequency [MHz]

Note: Sample NK1 as audio 44100 18_2M_2m.mp3 is a slowed down audio file of the two New Kent ionosondes crossing each other.