An Algorithm for Determining the Timing of Components and Superimposed Signals within the WWV/WWVH Scientific Test Signal

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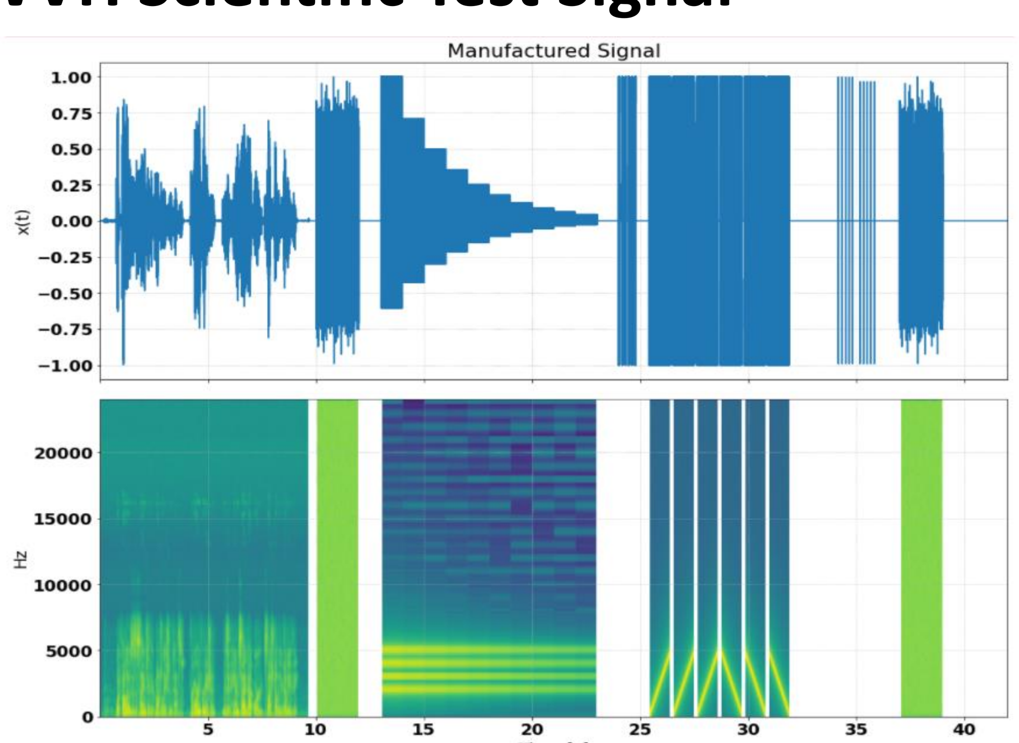
Introduction

- The United States National Institute of Standards and Technology (NIST) operates two HF broadcast radio stations with the goal of disseminating reference time and frequency standards to the world through ionospheric refractions of the transmitted signals. One station, WWV, is located near Fort Collins, CO. The second station, WWVH, is in Hawaii.
- The ionosphere is highly dynamic and variable. The propagated signals may be modulated in many ways. Through analysis of the signals received by volunteer radio operators at different locations, we can study what additional ionospheric measurements can be gleaned from the WWV/WWVH transmitter beyond carrier Doppler shift and time-of-flight of standard timing pulses.
- In collaboration with the Ham Radio Science Citizen Investigation (HamSCI) working group, starting November 15, 2021, the two stations begin transmitting the first version of the test signal on minute 8 of each hour on WWV, and minute 48 on WWVH.
- This project seeks to precisely identify the timing of each test signal component in the recorded data. Ultimately, there may exist multiple copies of the same components in the same recording, which is an indication of multipath propagation. Furthermore, since sunrises affect the ionosphere, which then affects radio waves that bounce off the ionosphere, the number of superimposed signals varies during those time periods. With a sufficient number of recordings at different times of the day, the phenomenon can be observed as it sweeps gradually across the United States. The results can help explain the broken symmetry between the transmitted signal and the received signal.

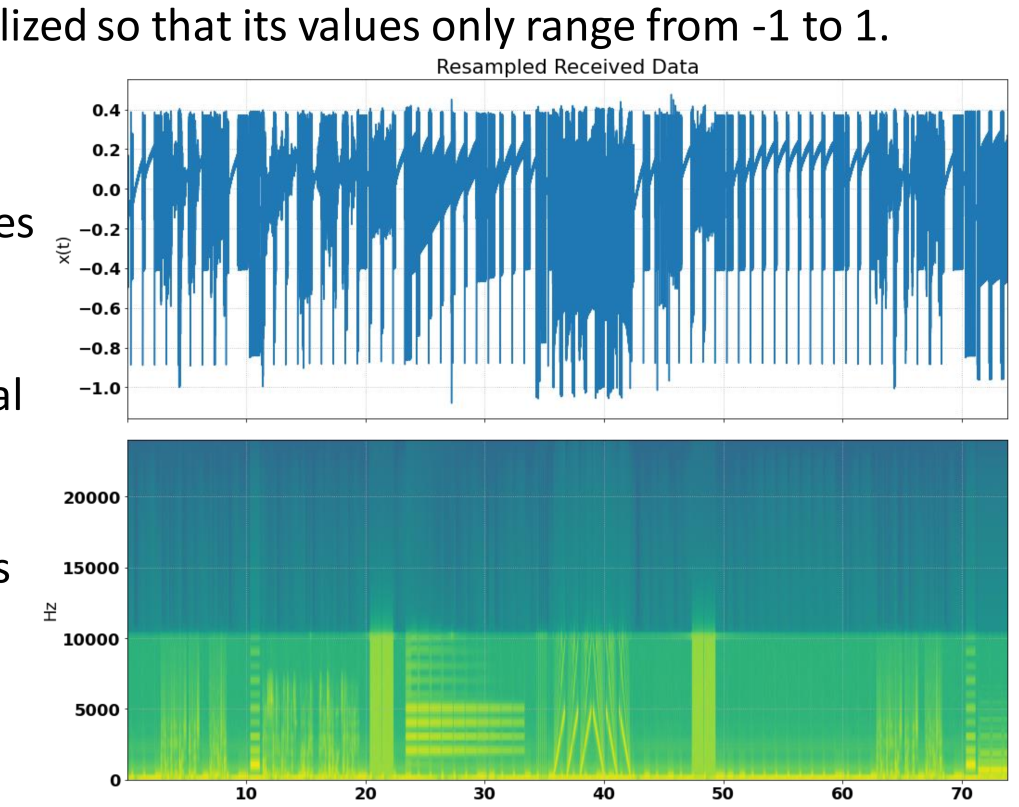
WWV/WWVH Scientific Test Signal



- 10 second voice announcement.
- Gaussian white noise (2 seconds).
- One second blank time.
- Phase-coherent 2, 3, 4, 5 kHz sine waves that drop down by 3 dB 9 times, 10 seconds total.
- One second blank time.
- An eight-second sequence consisting of linear up-chirps and down-chirps, generated with MATLAB: long is 5 kHz over 1 second (TBW = 5,000), short is 5 kHz over 0.05 seconds (TBW = 250). To wit: 3 short up, 3 short down, 0.5 seconds blank, 3 long up, 3 long down. 100 ms between chirps and at the end of each sub-sequence.
- 2 seconds blank time.
- A one-cycle burst at 2.5 kHz frequency, for time domain measurement, repeated 5 times over the course of 1 second; then the same for 5 kHz.
- One second blank time.
- Repeat of the pseudorandom Gaussian white noise sequence from (2) for synchronization.
- 3 seconds blank time (Collins et al., 2021).

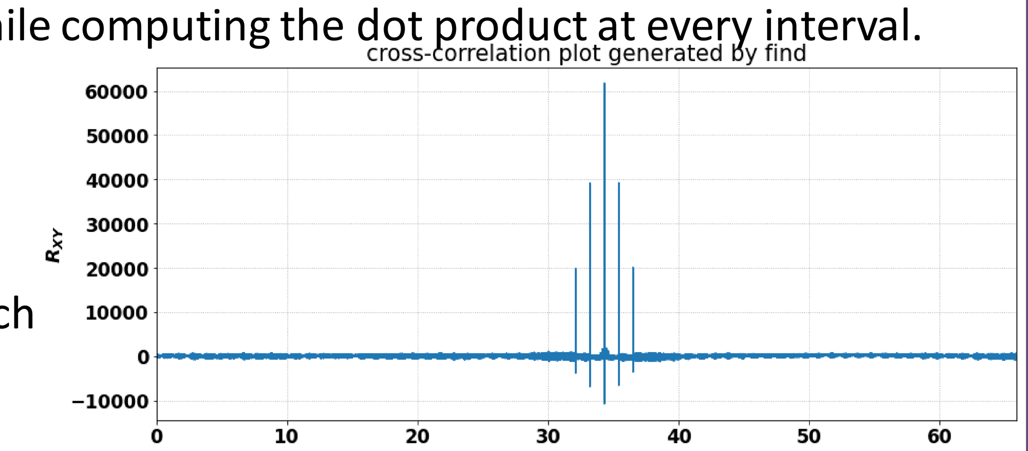
Preparing Collected Signals

- Before analysis can be done, all collected signals must be prepared to match the format required by the algorithm. This demo examines a recording from operator N6GN.
- Firstly, the received signals may be presented in either IQ data or AM signal. They must be converted to their pre-modulation form.
- Then, signals are normalized so that its values only range from -1 to 1.
- Finally, the received signals may have been sampled at different rates compared to the test signal. To avoid comparing the test signal with a stretched or compressed versions of itself, all received signals are resampled to match the sampling rate of 48,000 samples/sec.

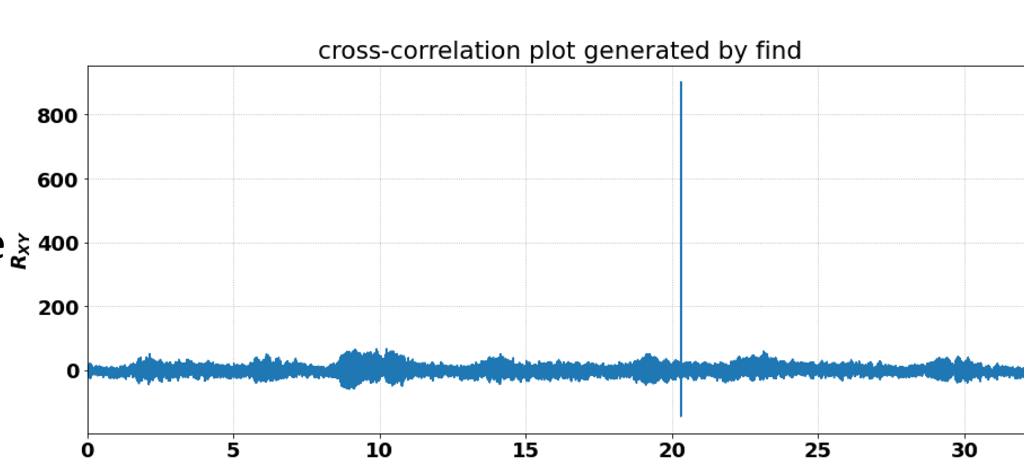


Timing Analysis

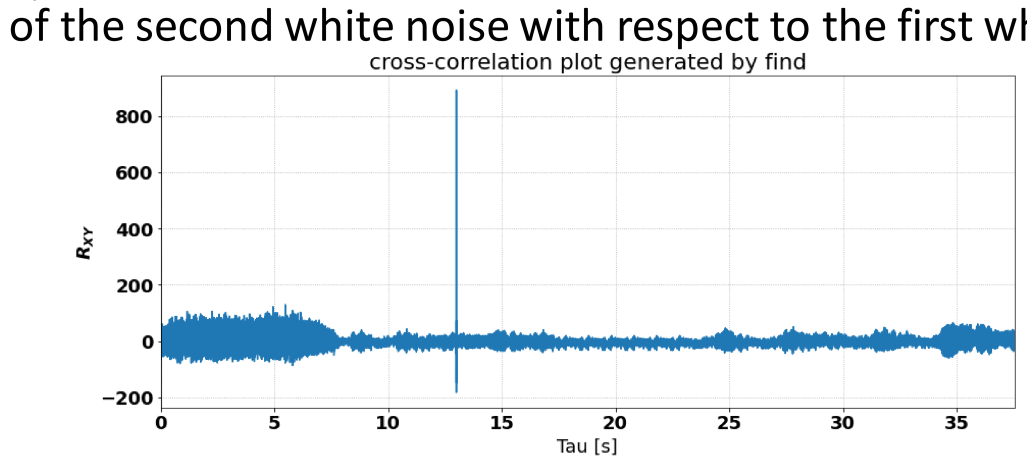
- For each signal component, the algorithm applies cross-correlation revealing the degree of similarity between two input signals. One signal is slid upon the other while computing the dot product at every interval.
- First, the timing of the chirps is identified. The plot shows a high correlation at t_{chirps} = 34.307458 seconds, which corresponds to the start of the chirps.



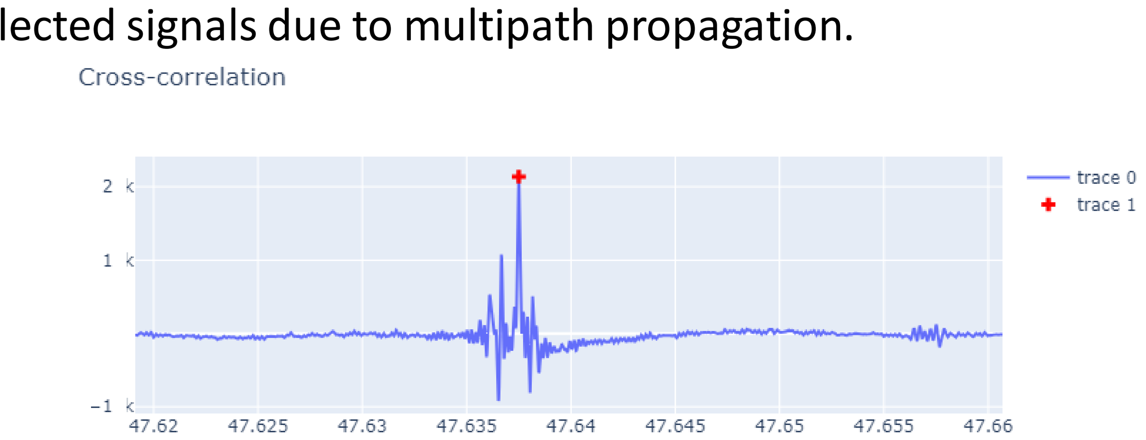
- Conveniently, the subsequent analysis can be done on two separate segments of the signals: pre-t_{chirps} and post-t_{chirps}. The first white Gaussian noise can be found in the former, and the second can be found in the latter.
- Performing a cross-correlation between the test white noise with the portion of the collected signal before the chirps reveals the timing of t_1 = 20.307375 seconds.



- It is useful to find the timing of the chirps with respect to the white noise. That is achieved by subtracting t_1 from t_{chirps} which results in a new t_{chirps} = 14.000083 seconds.
- A cross-correlation between the test white noise and the portion of the collected signal after the chirps reveals a t_2, which is with respect to the start of the chirps and can be inferred from the plot below. Adding the new t_{chirps} to t_2 results in a new t_2 = 27.000146 seconds, which is the timing of the second white noise with respect to the first white noise.



- The demo collected signal was collected by a station that is in line of sight with the WWV station, so multipath propagation cannot be observed. However, operator W2NAF is located in Pennsylvania, and a zoomed-in chirps correlation plot of signal from W2NAF shows that there are smaller peaks within milliseconds of the largest peaks. These peaks may correspond to the attenuated copies of the chirps in the collected signals due to multipath propagation.



Conclusion

- The algorithm can accurately identify the time which at which each individual component is present in the collected signals.
- The next possible improvement of the algorithm is the ability to analytically identify the total number of superimposed signals due to multipath, instead of utilizing manual identification.

References

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