An Algorithm for Determining the Timing of Components within the HamSCI-WWV/WWVH Scientific Test Signal

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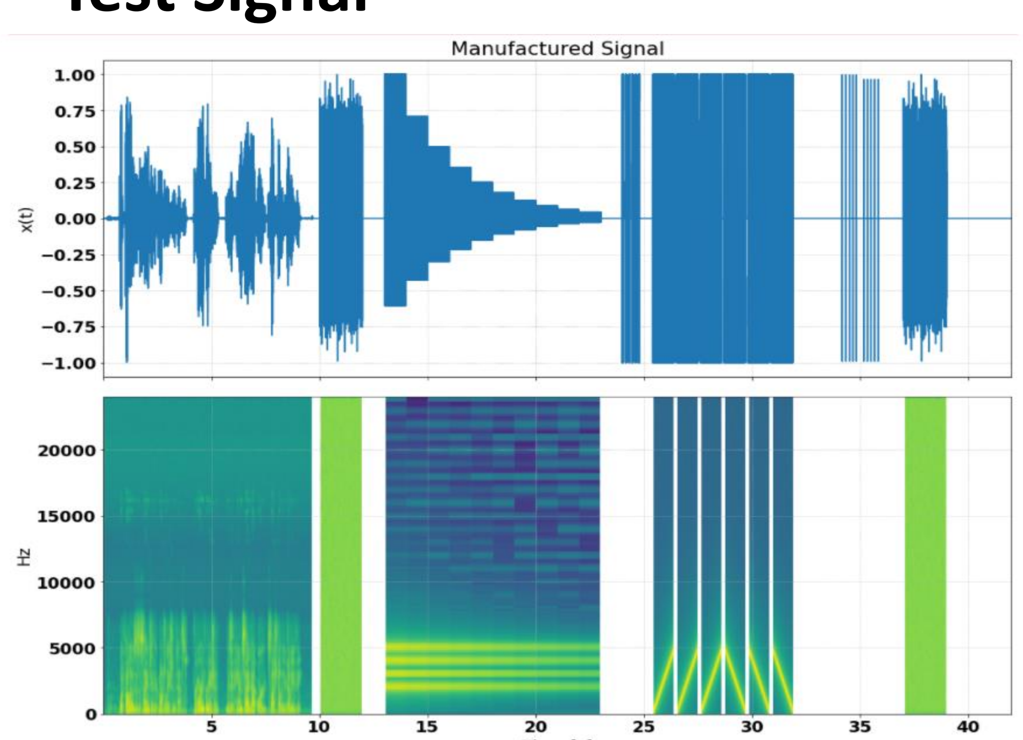
Introduction

- 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 interested 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 a 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. The results can help to explain the broken symmetry between the transmitted signal and the received signal.**

Test Signal

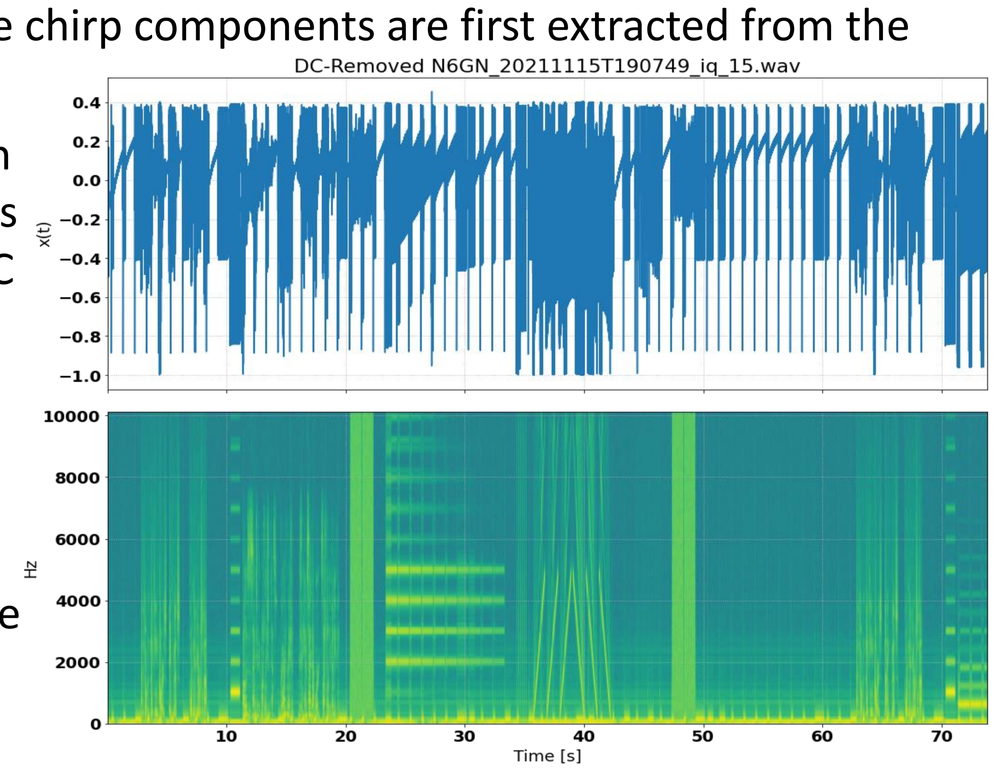
- 10 second voice announcement.
- Gaussian white noise (2 seconds).
- One second blank time.
- Phase-coherent 2, 3, 4, 5 kHz sine waves that drop down by 3 dB 9 times, 10 seconds total.
- One second blank time.



- 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).

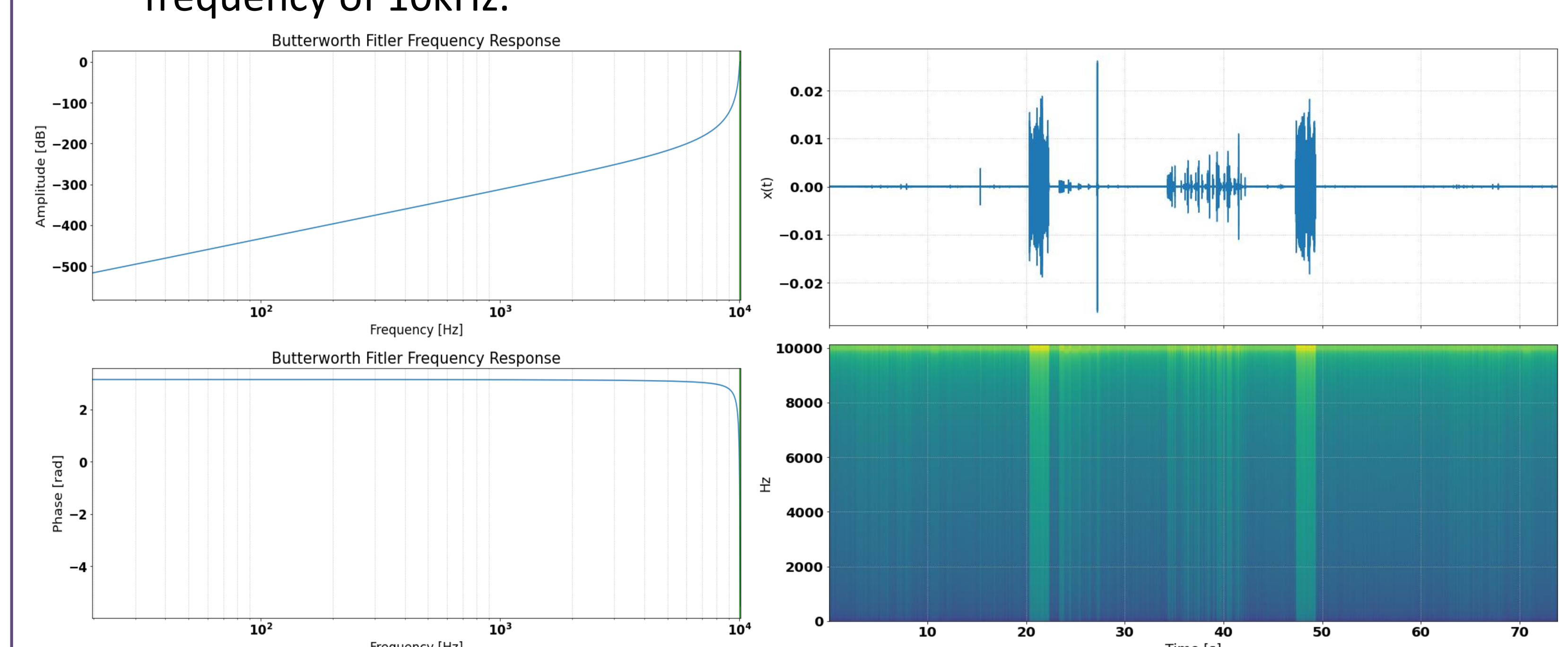
Signals Preparation

- The white noise and the chirp components are first extracted from the test signal.
- The received signal is an IQ signal, which requires demodulation. Then, DC offset removal is performed. Similarity between the transmitted and transmitted signals can already be observed due to the high-SNR received signal.

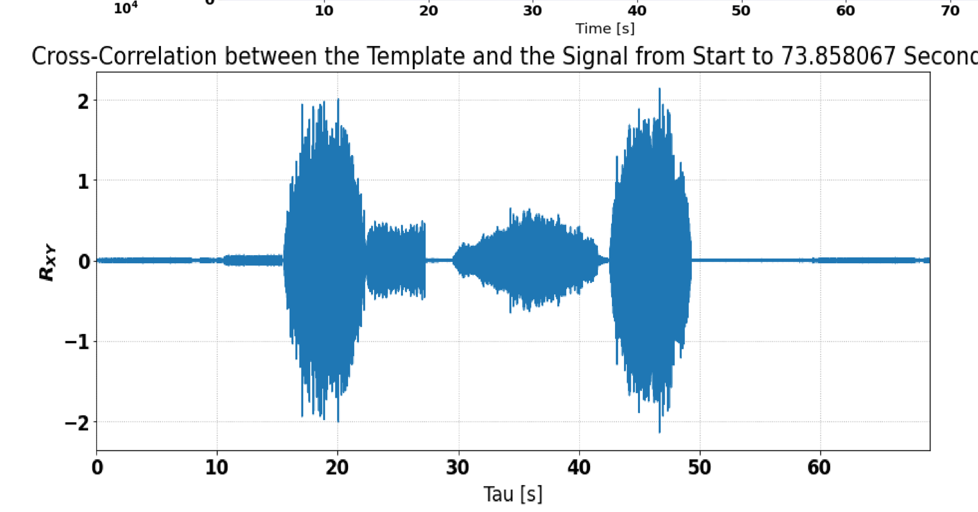


Analysis

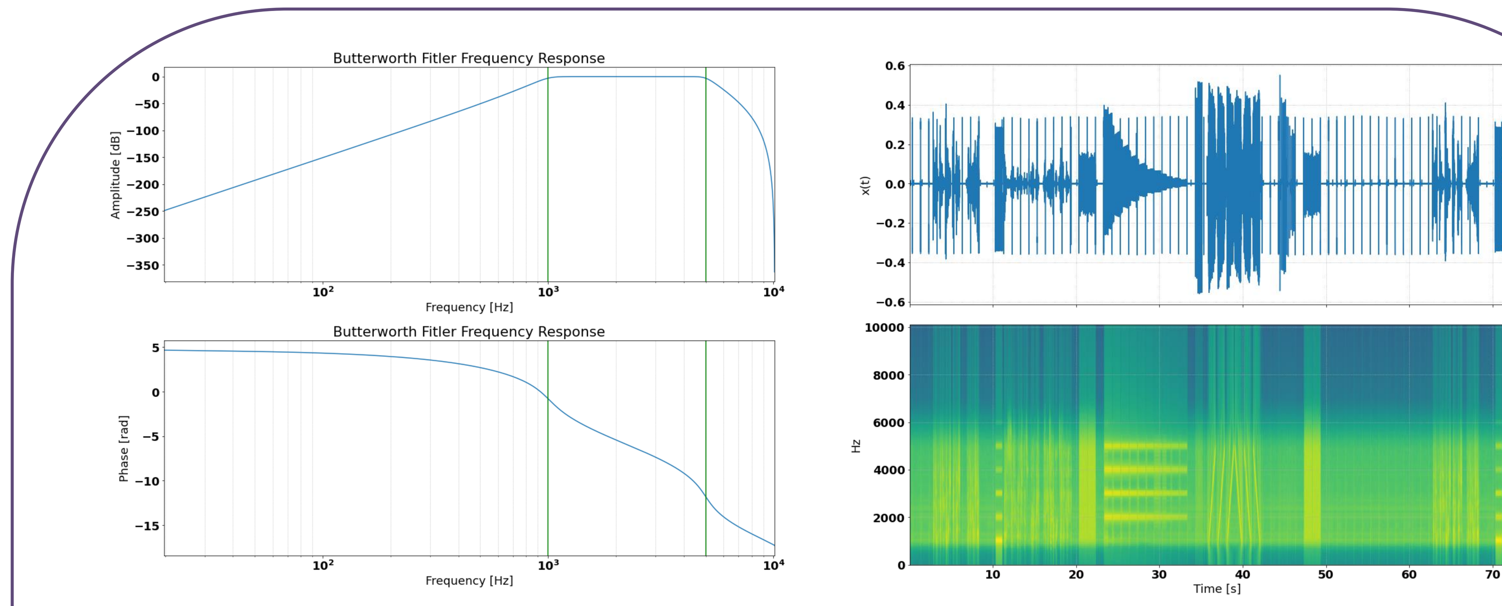
- First, we identify the timing of the white noises, which make it simpler to identify the chirps that happen in between. Since the white noise is unique at any point in time, we can use a Butterworth filter with a cutoff frequency of 10kHz.



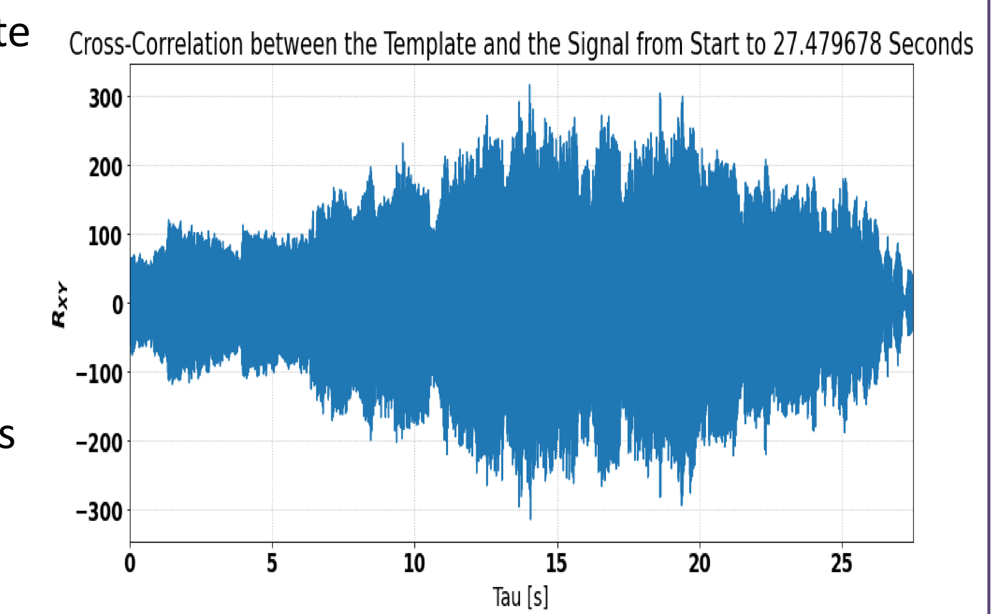
- Then, we cross-correlate the extracted white noise with the filtered signal. Another correlation is performed between the start of the filtered signal and the start of identified white noise.



- If there is another significant correlation value, that means the new Tau corresponds to the first white noise and the previous Tau corresponds to the second one.
- The start time of the first white noise is at 20.70 seconds. The start time of the second white noise with respect to the first is 27.48 seconds.
- Next, a bandpass filter of frequency range 1kHz-5kHz is applied to the demodulated received signal to reveal the chirps.



- Similarly, we cross-correlate the extracted chirps with the newly filtered signal, between the interval marked by the start of white noises identified in the previous step.
- The start time of the chirps with respect to the first white noise is at 14.04 seconds.



Conclusion

- The performance of the algorithm itself is estimated by calculating the SNR of each received signal and the corresponding confidence interval of the algorithm. The algorithm performs well only with high-SNR signals such as the one used for this demonstration.
- The team is gradually improving the algorithm to remedy this shortcoming. Part of that process includes a proper computation of the SNR.
- Enthusiasts may interact or even input their own data using the JupyterLab notebook at the URL below: https://mybinder.org/v2/gh/KCollins/wwv-h-wg/main

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