

## Detecting Voyager 1 signal in CT1DMK's wave file Yoshiyuki Takeyasu / JA6XKQ

April 2006, the report [1] that Luis Cupido, CT1DMK, had detected signals from Voyager 1 using a dish of only 6 meters was received with great surprise and admiration. His website features the reception recordings, accompanied by an invitation for others to attempt their own detection.

James Miller, G3RUH, subsequently detected the signal independently from these recordings and provided a detailed explanation of the methodology employed [2]. Because it was explained in detail, reading it made me feel like I understood it, and I neglected to actually try it myself.

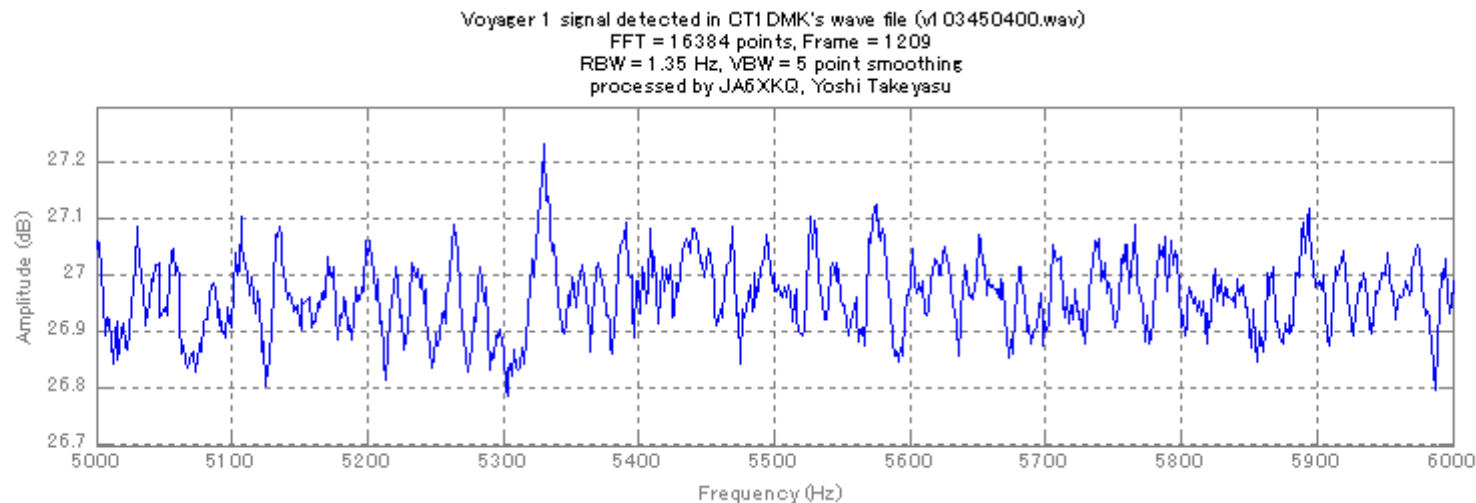
While this experiment remained in the queue for a significant period, following the procedures outlined by G3RUH eventually yielded similar results with relative ease (Figure-1). This report is limited to detailing the signal processing steps performed by myself. Regarding the underlying principles of G3RUH's signal processing, an appendix is planned for inclusion once permission for translation has been obtained.

## Signal Processing Flow

The overall flow of the signal processing is as follows:

- 1 Calculation of the amplitude-frequency response deviation of the receiver passband.
- 2 Fast Fourier Transform (FFT).
- 3 Equalization of the FFT results using the characteristics calculated in step 1.
- 4 Frequency shifting of the FFT results to compensate for the Doppler shift.
- 5 Integration with the results of the previous FFT frame.
- 6 Repetition of steps 2 through 5, followed by averaging by the total number of frames.
- 7 Smoothing across adjacent frequencies (equivalent to the video filter of a spectrum analyzer).

The primary objective of this signal processing is to improve the Signal-to-Noise (S/N) ratio of the weak signal through time integration (summation).



**Figure-1** : Voyager 1 signal detected from CT1DMK's recording (peak waveform at 5329 Hz)

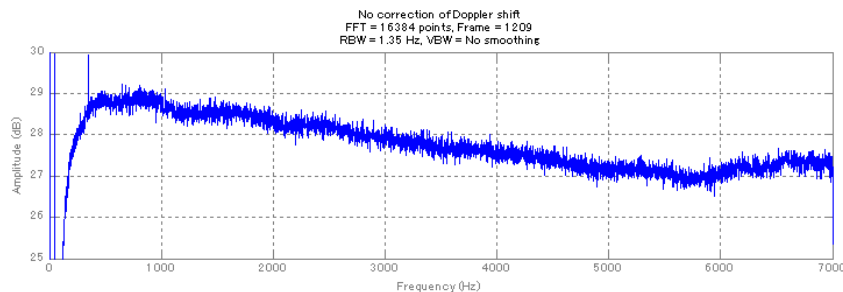
## Receiver Passband Amplitude-Frequency Deviation and Equalization

The amplitude-frequency response deviation of the receiver passband is determined first. It should be noted that this description was formulated after the full scope of the signal processing became clear; it was not an initial assumption. Through experimentation, it became evident that compensation for the receiver passband deviation was necessary.

**Figure-2** shows the result of applying a simple FFT to the recording file (v103450400.wav). With a sampling frequency of 22050 Hz and a 16384-point FFT, the frequency resolution is 1.35 Hz. Given the 900-second duration of the wave file, 1209 frames of 16384-point FFTs are processed. **Figure-2** represents the simple average of these 1209 FFT frames.

If there were no Doppler shift in the received signal, the signal spectrum would emerge in **Figure-2** due to the integration effect of the 1209 additions. However, the target signal is dispersed due to a Doppler shift of -713.11 Hz. For comparison with **Figure-1**, **Figure-3** illustrates the same data with an expanded frequency axis. Based on the final results, the signal is expected to be spread between 5300 Hz and 4600 Hz, and the display range was adjusted accordingly.

From the results in **Figure-2**, it is observed that the receiver passband exhibits an amplitude-frequency deviation of approximately 2 dB. At the Doppler shift frequency of 713.11 Hz, the deviation is approximately 0.25 dB, which degrades the integration gain.



**Figure-2** : Receiver passband amplitude-frequency deviation - without smoothing

To equalize this deviation, using **Figure-2** directly is problematic due to high noise levels. Therefore, equalization is performed using characteristics where noise has been removed. **Figure-4** shows the result of applying smoothing across 128 adjacent frequency points to the data in **Figure-2**.

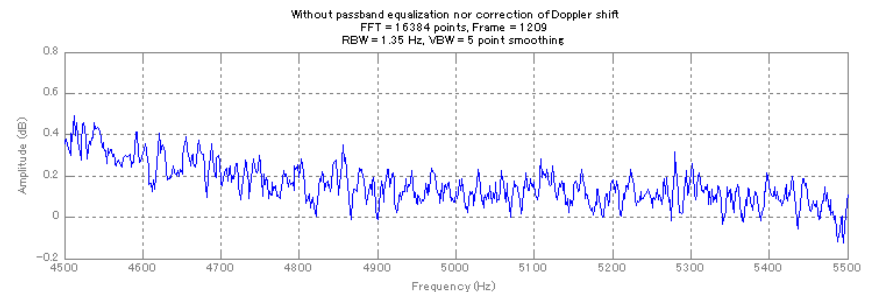
Equalization is then executed by multiplying the FFT results by the inverse characteristics of **Figure-4**.

## Doppler Shift Compensation

Since the target signal exhibits a Doppler shift, it must be corrected before the results are summed. This process is schematically illustrated in **Figure-5**.

The upper waveform in **Figure-5** represents the recorded wave file, where the horizontal axis denotes time. An FFT is applied to this waveform using frames of 16384 samples. At a sampling frequency of 22050 Hz, the duration of a single frame is 743 milliseconds.

The lower-left portion of **Figure-5** schematically represents the signal converted into the frequency domain. As the target signal is predicted to have a Doppler shift rate of -0.7923 Hz/sec, the frequency decreases with each FFT frame.



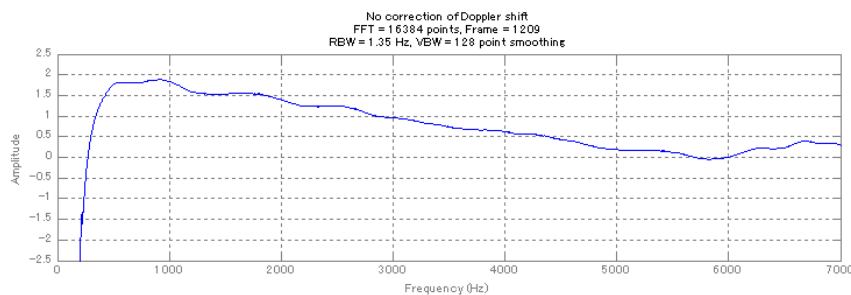
**Figure-3** : Receiver passband amplitude-frequency deviation - frequency axis expanded

The lower-right portion of **Figure-5** illustrates the compensation for this frame-by-frame Doppler shift. The process of shifting the decreased frequency upward is performed in the frequency domain after the FFT. This is achieved by treating the FFT result as a single-row array and shifting the array elements. Specifically, elements are added to the beginning of the array according to the shift amount, while a corresponding number of elements are removed from the end.

A critical point is the relationship between the Doppler shift frequency, the FFT resolution, and the number of FFT frames. In other words: how many samples are required for the Doppler shift to equal the FFT resolution (1.35 Hz)? Given a rate of -0.7923 Hz/sec, the array elements of the FFT result should be shifted by one element every 1.698 seconds (or 37454 samples).

Since the 37454 samples required for Doppler compensation and the 16384 samples of the FFT frame are not related by an integer multiple, the compensation includes rounding errors.

While this report performs Doppler shift compensation in the frequency domain post-FFT, it differs from G3RUH's method, which applies compensation to the wave file data in the time domain prior to the FFT. **Figure-6** shows the signal detected after Doppler shift compensation.

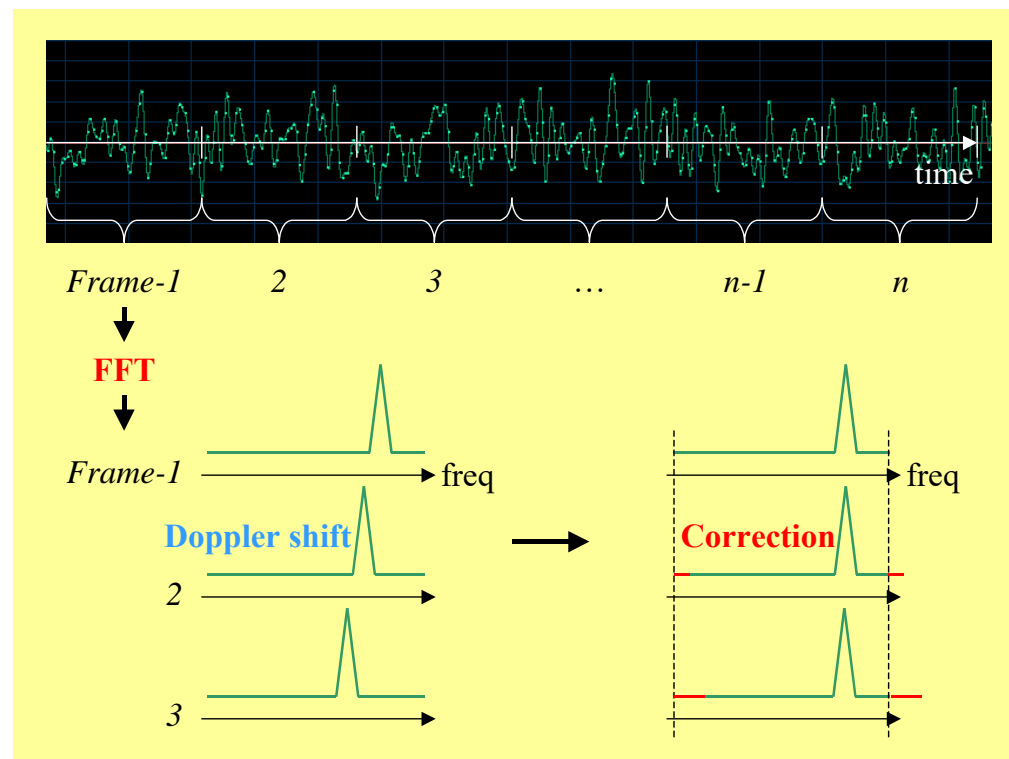


**Figure-4** : Receiver passband frequency characteristics - with smoothing

## Video Filter

In the state shown in **Figure-6**, a signal-like component is visible, but identification is difficult due to spike-like noise. Since the target signal appears to have a bandwidth wider than the FFT resolution, smoothing across adjacent frequencies is effective for removing these spikes. This is equivalent to the video filter used in a spectrum analyzer.

**Figure-1** shows the result of applying smoothing across 5 adjacent points to the data in **Figure-6**. The spike-like noise is reduced, and the spectrum believed to be the target signal can be identified at 5329 Hz.



**Figure-5** : FFT and Doppler shift compensation

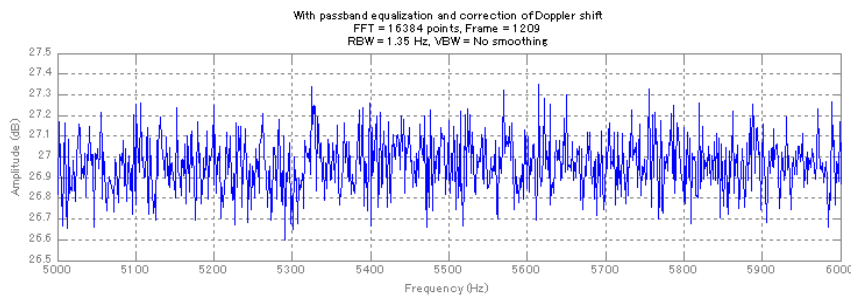
## Summary

By applying signal processing to CT1DMK's reception recording in accordance with G3RUH's explanation, a Voyager 1 signal equivalent to their results was detected.

This experiment highlights two significant points. Signal processing consists of a front-end and a back-end. The first point is the excellence of CT1DMK's receiving facilities as a front-end. While a superior G/T is essential, post-processing as a back-end cannot function unless the total receiving system demonstrates high long-term stability in gain, frequency, and antenna tracking. Secondly, the established signal processing methods and parameters explained by G3RUH allowed the same results to be achieved without the need for trial and error.

Detection was likely possible because of *the conviction that "the signal is there"*. Although this was merely a tracing of the achievements of predecessors, it allowed for the re-experience of both surprise and profound emotion.

(July 26, 2009 - Japanese edition, Second Edition)  
(May 6, 2026 - English translated version)



**Figure-6** : Signal detected with Doppler shift compensation

## References

- [1] Luise Cupido, CT1DMK, "Receiving the deep space spacecrafts."  
<https://www.qsl.net/ct1dmk/dsn.html>
- [2] James Miller, G3RUH, "Independent data analysis."  
[https://www.qsl.net/ct1dmk/v1\\_ruh.txt](https://www.qsl.net/ct1dmk/v1_ruh.txt)