

## Detecting Voyager 1 signal in CT1DMK's wave file

### — Consideration on frequency stability

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Upon applying signal processing to the recordings captured by CT1DMK, following the methodology described by G3RUH, the Voyager 1 signal was detected with results equivalent to their findings. This process highlighted two critical points [1]: the front-end and the back-end of signal processing. The excellence of CT1DMK's front-end receiving equipment lies in:

- High G/T and its stability
- Frequency stability
- High-precision and high-stability antenna tracking

The core of the signal processing is Doppler correction based on predicted values. If the frequency stability of the aforementioned receiving system is poor, this correction process itself becomes ineffective.

To address the question, "What level of frequency stability is actually required?", a simulation was conducted using the same computational processing employed for signal detection.

### Simulation and Assumptions

CT1DMK's reception, the receiver frequency remains fixed, and Doppler correction is performed during signal processing. Conversely, if Doppler correction were performed by controlling the receiver frequency using Doppler predictions, the recorded signal would contain no Doppler shift, allowing the signal processing to consist simply of applying an FFT and integrating. In either case, if the receiver frequency is unstable, for instance, due to frequency drift the results of the Doppler correction based on predicted values

will contain errors.

The simulation evaluates this impact by incorporating the receiver's frequency drift into the Doppler prediction values. The actual Doppler prediction is  $-0.7923$  Hz/sec, resulting in a total Doppler shift of  $-713.11$  Hz over the 900-second recording duration. Assuming the stability of the receiver's local oscillator is  $1E-9$  / 1000 sec, the frequency drift at the receiving frequency of 8.4 GHz would be  $8.4$  Hz / 1000 sec. Converting this to a drift rate per second yields  $8.4E-3$  Hz / sec. This value is added to the Doppler prediction, and the Doppler correction is calculated at  $-0.8007$  Hz / sec.

Essentially, the processing is executed assuming that the 900-second Doppler shift of  $-713.11$  Hz appears as  $-720.63$  Hz due to the receiver's frequency fluctuations.

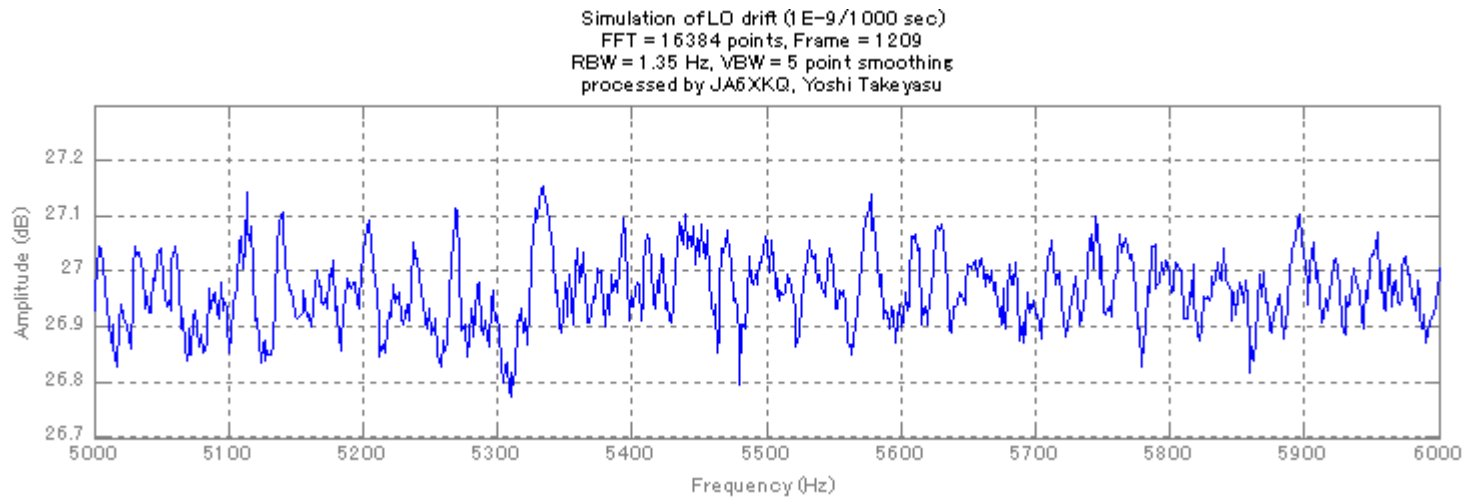
The assumed local oscillator stability of  $1E-9$  / 1000 sec is typical for a general crystal oscillator. A frequency drift of  $8.4$  Hz over 1000 seconds in the 8.4 GHz band is considered a realistic occurrence if no special measures are implemented.

### Simulation Results

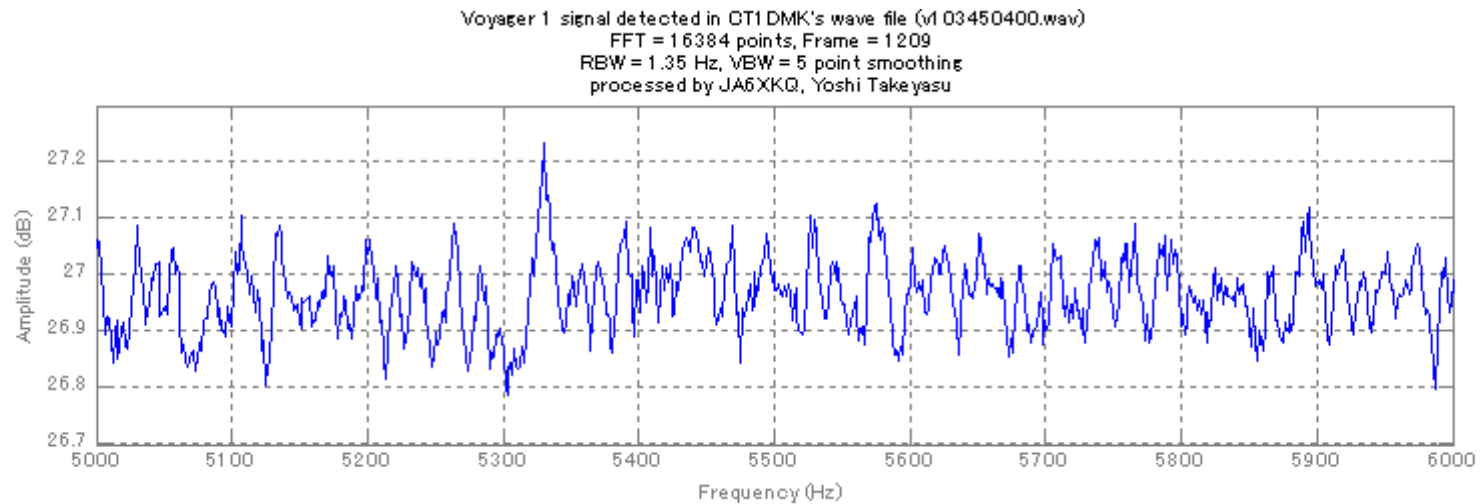
No changes to the signal processing software program are required; the process is completed simply by replacing the original Doppler rate of  $-0.7923$  Hz / sec with  $-0.8007$  Hz / sec. There are no changes to the receiver passband correction or the video filter.

**Figure-1** shows the result of simulating the receiver's frequency drift. For comparison, **Figure-2** shows the original result, representing the case without frequency drift.

In **Figure-1**, a peak waveform can be observed at 5329 Hz, similar to **Figure-2**, but it does not significantly differ from other peaks. Without prior knowledge of the results from **Figure-2**, identifying this as the target signal would be problematic.



**Figure-1** : Simulation result of frequency drift



**Figure-2** : Voyager 1 signal detected from CT1DMK's recording (peak at 5329 Hz) - without frequency drift

## Summary

The simulation results indicate that a receiver local oscillator stability of  $1\text{E-}9 / 1000$  sec is insufficient. How much stability is then required? Given an FFT resolution of 1.35 Hz, the impact on processing results should be negligible if the frequency drift over the 900-second processing period remains below this resolution. Converted to stability over 1000 seconds in the 8.4 GHz band, this equates to  $1.78\text{E-}10 / 1000$  sec. It is concluded that a stability level one order of magnitude higher than that of a standard, non-stabilized crystal oscillator is necessary.

The AMSAT-DL team, including G3RUH, received the Voyager 1 signal at Bochum in March 2006, prior to CT1DMK's reception. These efforts were introduced by Achim Vollhardt (DH2VA/HB9DUN) of the AMSAT-DL team at the AMSAT-UK Colloquium in August 2006 [2]. According to that report, the required frequency stability is cited as  $1\text{E-}10 / 1000$  sec. The local oscillator used in the actual receiver utilized a rubidium oscillator as a reference. The receiver used by CT1DMK is also estimated to possess a stability of approximately  $1\text{E-}10 / 1000$  sec.

This report examined the required frequency stability for a receiver based on Doppler shift predictions. Doppler correction is the cornerstone of signal processing. As noted in G3RUH's commentary, any inaccuracy in the baseline Doppler shift predictions themselves results in processing errors [3]. It is understood that both the frequency stability of the receiver and the accuracy of the Doppler shift predictions are vital for processing signals from DSN probes.

(August 14, 2009 – First Japanese edition)  
(August 15, 2009 – Second Japanese edition)  
(May 6, 2026 – English translated version)

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## References

- [1] Yoshiyuki Takeyasu, JA6XKQ, "Detecting Voyager 1 signal in CT1DMK's wave file."  
[http://www.terra.dti.ne.jp/~takeyasu/Voyager1\\_2\\_EN.pdf](http://www.terra.dti.ne.jp/~takeyasu/Voyager1_2_EN.pdf)
- [2] Achim Vollhardt, DH2VA / HB9DUN  
[http://www.amsat-dl.org/pic/gallery2/d/6706-3/surrey2006\\_folien20-38.pdf](http://www.amsat-dl.org/pic/gallery2/d/6706-3/surrey2006_folien20-38.pdf)
- [3] James Miller, G3RUH, "Independent data analysis of Voyager 1 signal in CT1DMK's wave file."  
[https://www.qsl.net/ct1dmk/v1\\_ruh.txt](https://www.qsl.net/ct1dmk/v1_ruh.txt)

## Addendum – Doppler Shift, Resolution, and Frequency Stability

The statement in the summary "Given an FFT resolution of 1.35 Hz, the impact on processing results should be negligible if the frequency drift over the 900-second processing period remains below this resolution" seem like a "chicken and egg" scenario. A question may arise: "Could the FFT resolution simply be lowered to reduce the impact of frequency drift?"

The concept of this signal processing is to increase the C/N ratio by increasing FFT resolution (narrowing the RBW) to lower the in-band noise power, followed by time integration. Therefore, the FFT resolution should be as high as possible. But how high is "as possible"? Since the signal itself has a Doppler shift ( $-0.7923$  Hz / sec), it is necessary to ensure the Doppler shift remains within the resolution during a single FFT process. It is inefficient to try to recover water once it has spilled from the bucket bin.

The value of  $\text{RBW} = 1.35$  Hz is derived from applying a 16384 ( $2^{14}$ ) point FFT to a signal with a sampling frequency of 22,050 Hz. One FFT frame lasts 0.743 seconds. During this interval, the Doppler shift is 0.589 Hz, which fits within the FFT resolution.

If the FFT points were doubled to 32768 to further improve C/N ( $\text{RBW} =$

0.673 Hz), one FFT frame would last 1.486 seconds, during which the Doppler shift would reach 1.177 Hz. Consequently, the Doppler shift would exceed the resolution.

Therefore, based on these numerical examples,  $RBW = 1.35$  Hz is determined to be the resolution limit for this signal processing. The Doppler shift rate of the target signal is the primary factor, which then dictates the optimal FFT resolution. Since these relationships define the frequency stability required of the hardware, there is no "chicken and egg" dilemma.

(August 15, 2009 – Addendum in Japanese version)  
(May 6, 2026 – English translated version)