

Spur Detection, Analysis and Removal Stable32

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Introduction

Stable32 Version 1.54 and higher has the capability to detect, analyze and remove discrete spectral components (spurs) in its Power (power spectral density, PSD) function. This supports automatic spur detection for all the PSD types ($S_y(f)$, $S_\phi(f)$, $S_x(f)$ and $L(f)$), along with graphical representation of discrete spectral lines on PSD plots, identification of the largest spur in a plot message, and a table of all detected spurs written to the Windows clipboard. It also supports removal of the detected spurs from the original phase or frequency time domain data.

Spur Detection

Spurs are detected by scanning the results of a PSD analysis and comparing the value in each spectral bin against an adjustable spur limit. That comparison is made after “prewhitening” the PSD results by subtracting a power law noise fit and thus removing its trend. The spur detection starts at the lowest unskipped Fourier bin and searches upward for a PSD value above the threshold. If a spur is found, the algorithm locates the bin with the local peak, and uses a parabolic fit to the adjacent points to determine a more exact value for the PSD value and Fourier frequency, and stores them and the center bin index in a spur array. The search process then moves off the peak and continues searching for additional spurs. Up to 100 spurs can be detected by this Stable32 spur detection algorithm.

Spur Analysis

Three complementary means are used to present the results of the spur search, all under the control of options set in the Stable32 Power Spectrum Plot dialog box. The detected discrete spectral components can be shown as heavy vertical green lines on the PSD plot with their height indicating the spur amplitudes, which are corrected for their narrowband energy (e.g., shown as dBc rather than dBc/Hz). These lines extend from the bottom of the plot if the spur amplitude is below the power law noise fit, and from the noise fit if the amplitude is above it. Note that it is possible for the former to be completely off the plot scale. The number of spurs, and the amplitude and frequency of the largest spur can be shown in a message on the plot. In addition, a complete table of the spur number, FFT bin, Fourier frequency and log amplitude, along with other relevant information, is written as a text file to the Windows clipboard whenever spur detection is activated.

Examples of Spur Detection and Analysis

Examples of these Stable32 spur detection and analysis features are shown in the Figures 1-3 below.

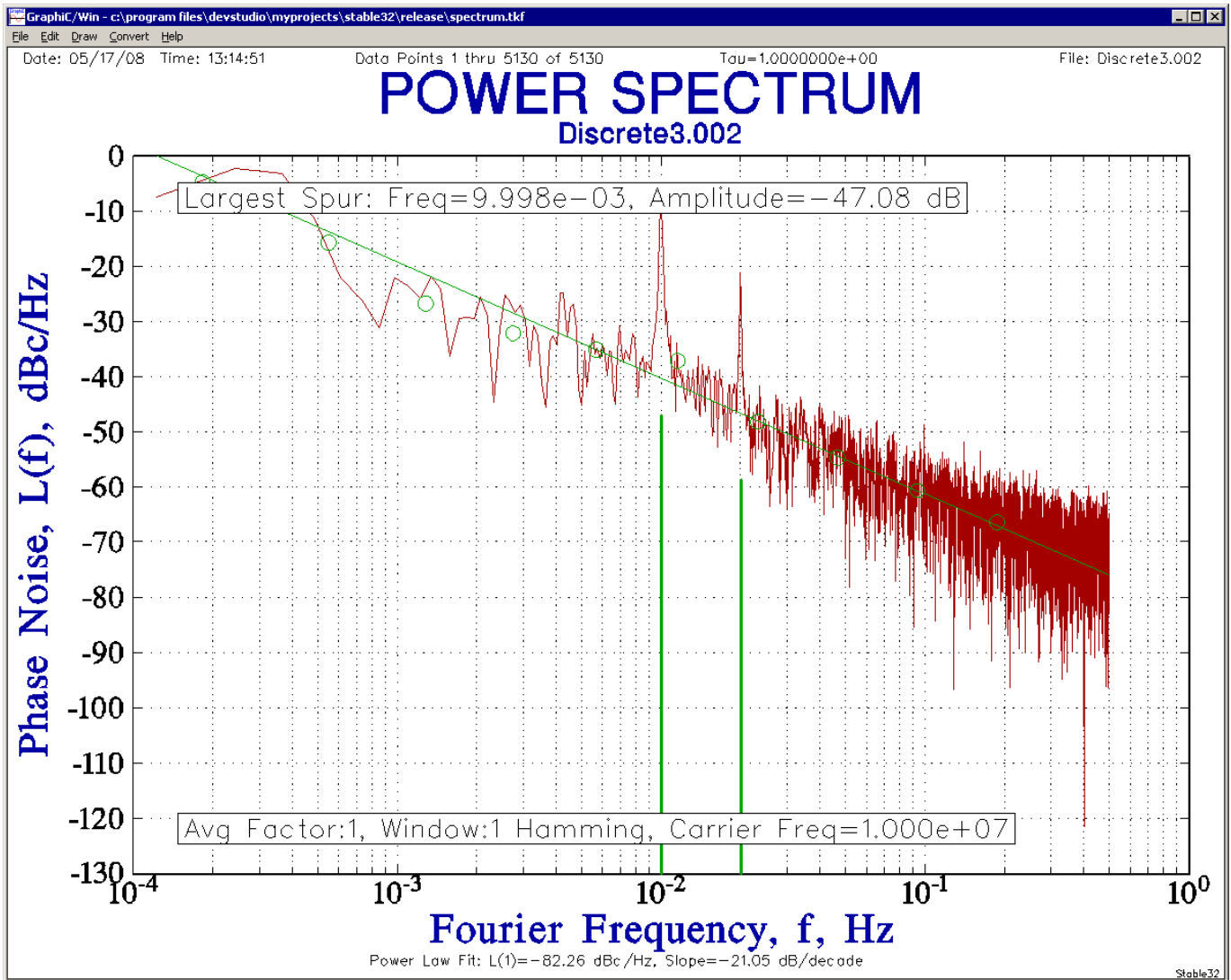


Figure 1. L(f) Plot with Spur Detection

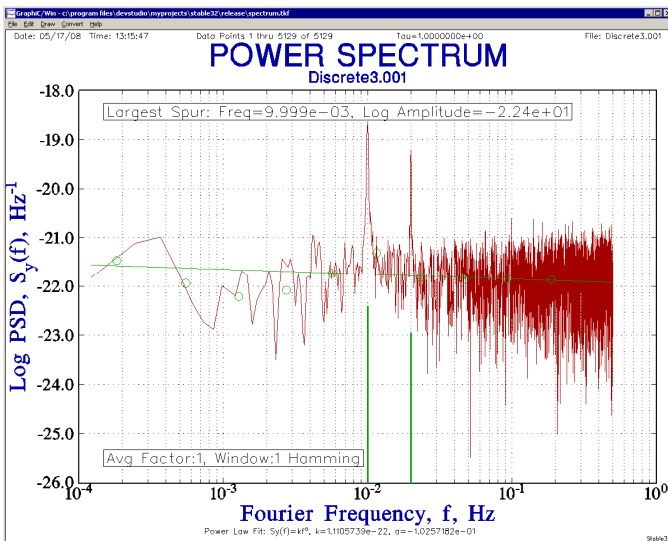


Figure 2. $S_y(f)$ PSD Plot with Spur Detection

File: Discrete3.001
 PSD Type: $S_y(f)$
 Log Spur Threshold = 2.000e+00 (x100.00)
 ENBW = 1.664e-04 Hz, Log NB Corr = -3.78
 PSD Discrete Spurs:

Spur #	FFT Bin #	Spur Frequency Hz	Discrete Amplitude Log df/f
1	81	9.999e-03	-2.24e+01
2	163	2.000e-02	-2.30e+01

Figure 3. Clipboard Spur Analysis File

Options

The Stable32 spur detection and analysis options are set in the Power Spectrum Plot dialog box and the Options page of the Configure property sheet. Besides the normal PSD settings, the former contains a Spurs checkbox that activates spur detection. The spur plot message is controlled by a combination of this checkbox and the Message Position list box. The spur detection threshold (in dB above the power law noise fit) is set in the Spur Threshold in the latter. The Power Spectrum Plot dialog box also has two new checkbox controls to remove spurs from PSD plot and from the time domain data. These controls are shown in Figures 4 and 5 below.

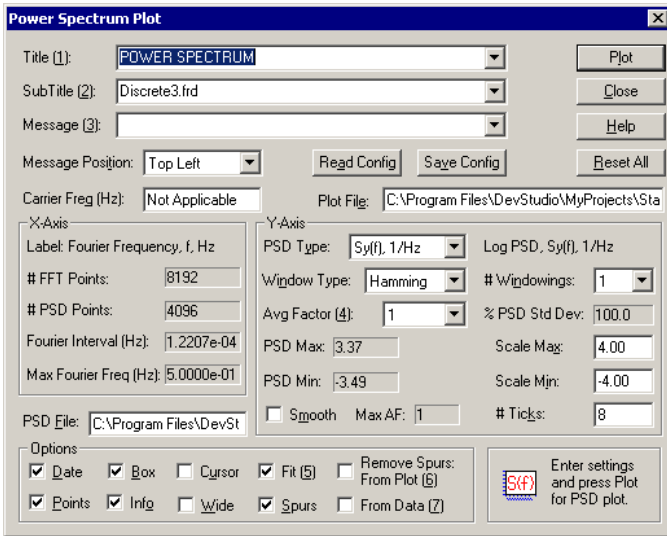


Figure 4. Power Spectrum Plot Dialog Box

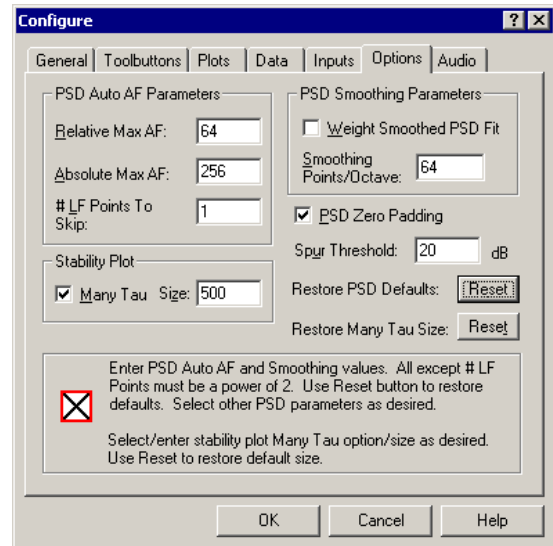


Figure 5. Options Property Sheet Page

Spur Removal

Spurs removal is done by performing a complex FFT on the real time domain data in sections corresponding to the selected averaging factor, replacing spurs with real and imaginary conjugate symmetric FFT values of zero, and then performing an inverse FFT to obtain the corrected real time domain data. This process is shown in Figure 6 below for an averaging factor of 4.

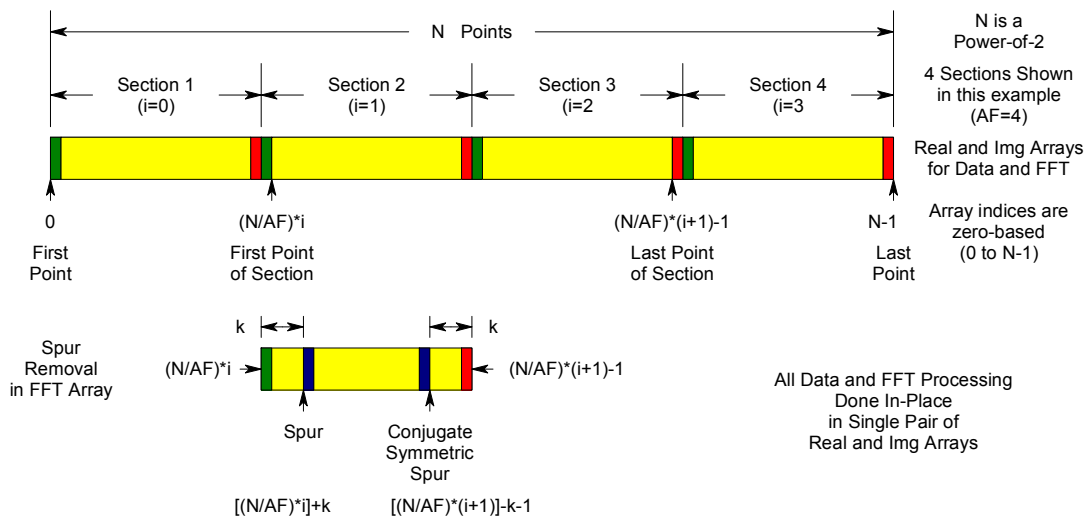


Figure 6. Spur Removal Data and FFT Arrays

Examples of Spur Removal

The following example shows another set of simulated frequency data that has periodic interference.

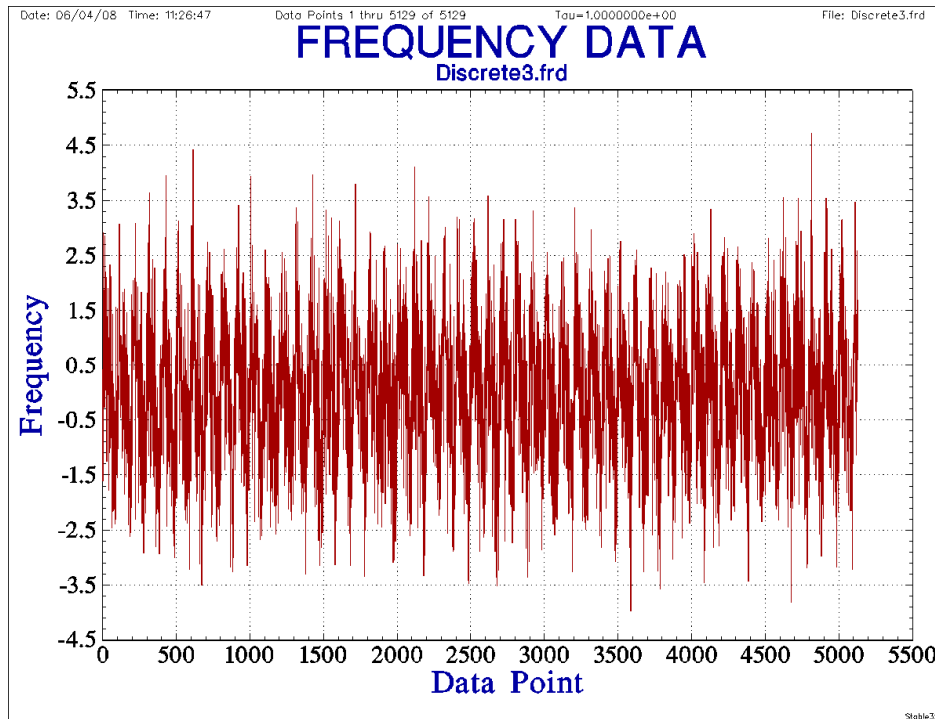


Figure 7.
Frequency Data
with Periodic Interference

Two discrete spectral components can be clearly seen in the default PSD plot for these data with the Spurs checkbox activated:

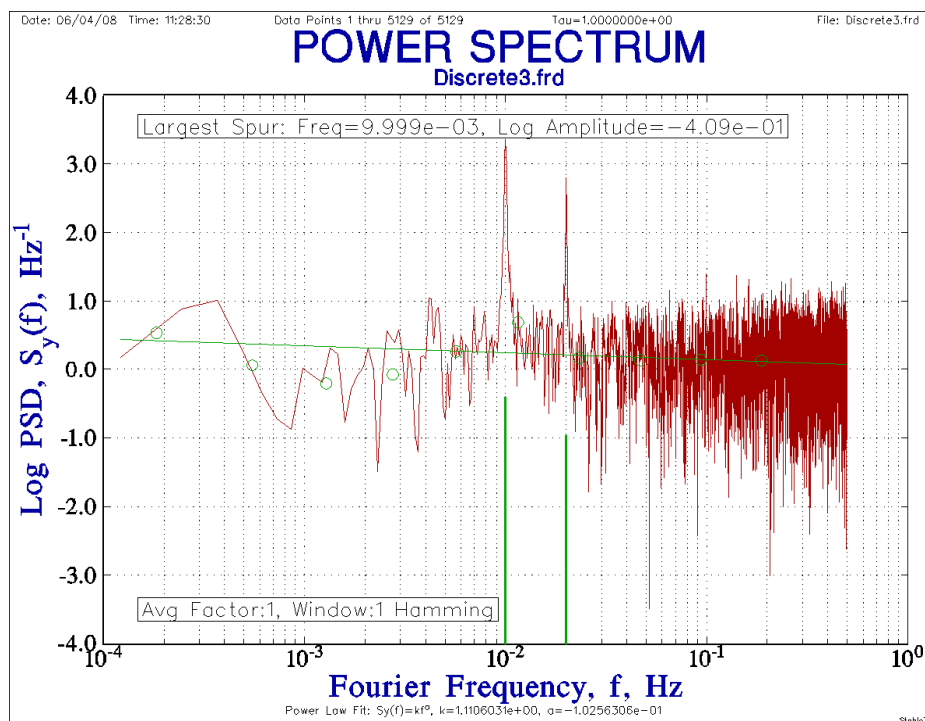


Figure 8. PSD of Frequency Data Showing Two Spurious Components

These PSD data are automatically written to a data file. The spurs are also reported in the following text that is automatically written to the Windows clipboard as shown in Figure 9 below.

```

File: Discrete3.frd
PSD Type: Sy(f)
Avg Factor:1, Window:1 Hamming
Log Spur Threshold = 1.500e+00 (x31.62)
ENBW = 1.664e-04 Hz, Log NB Corr = -3.78
PSD Discrete Spurs:
Spur FFT   Spur      Discrete
Bin  Frequency Amplitude
#    #          Hz          Log df/f
1    81    9.999e-03 -4.09e-01
2    163   2.000e-02 -9.65e-01
    
```

Figure 9. Analysis of Spurious Components in Frequency Data

The spurs are large enough to have a significant effect of the time domain stability, as shown in the All Tau Allan deviation plot of Figure :

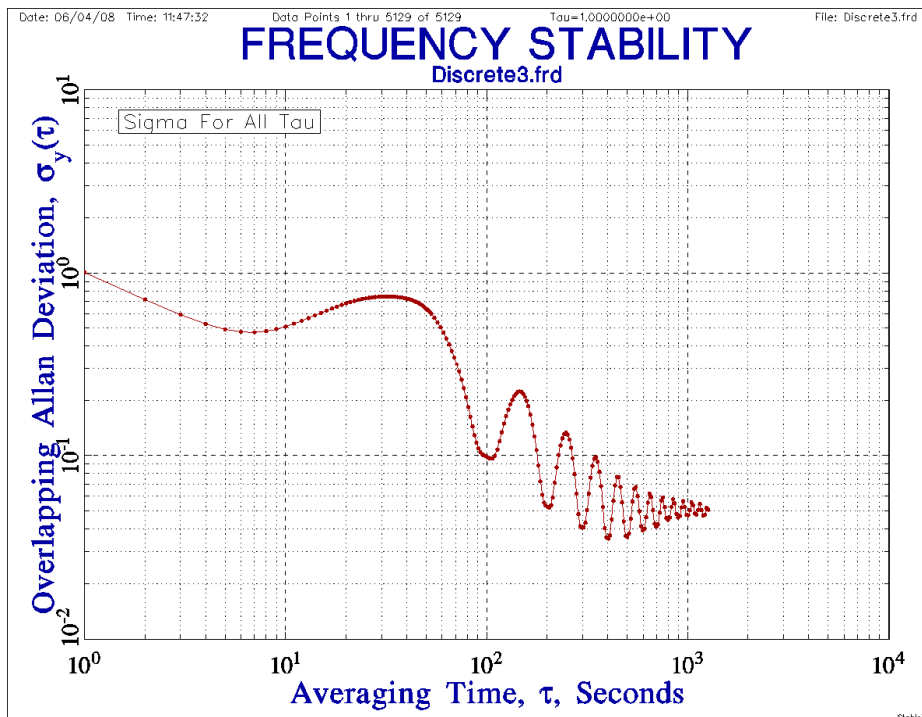


Figure 10. All Tau Allan Deviation Plot Showing Periodic Interference

The ADEV plot begins at the correct simulated white FM noise value of 1.0 at $\tau = 1$, but then shows a strong composite periodic component rather than the normal $\tau^{-1/2}$ slope.

Activating the Remove Spurs From Plot checkbox changes the PSD plot to the following:

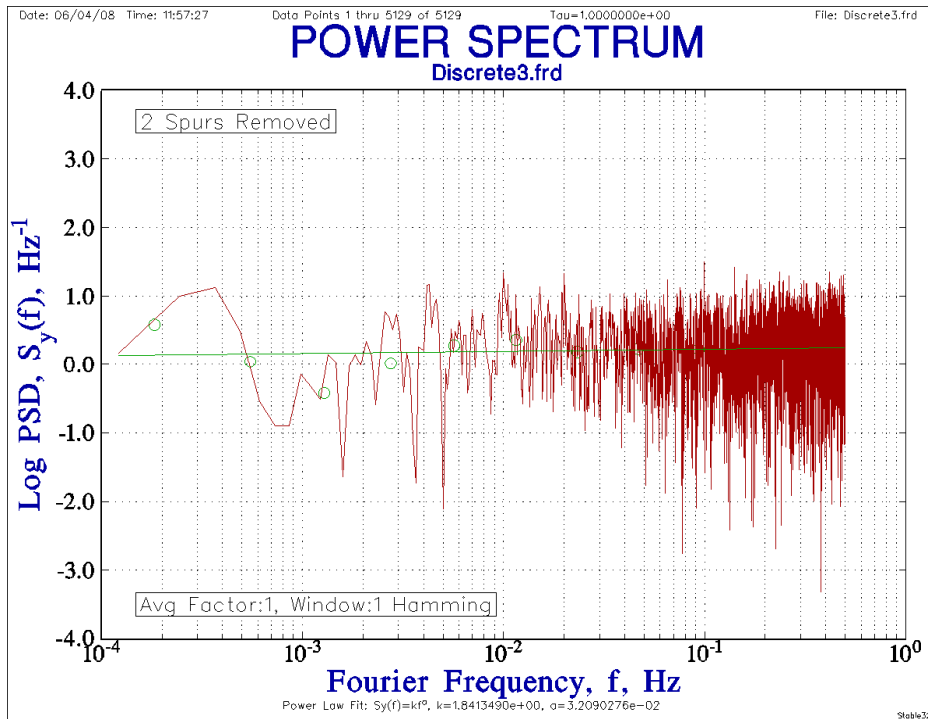


Figure 11. PSD Plot with Spurs Removed

The two spurs (denoted by faint yellow points) are removed down to the 1.5 log $S_y(f)$ threshold level.

The corrected frequency data is available for further analysis. The frequency data no longer has obvious interference:

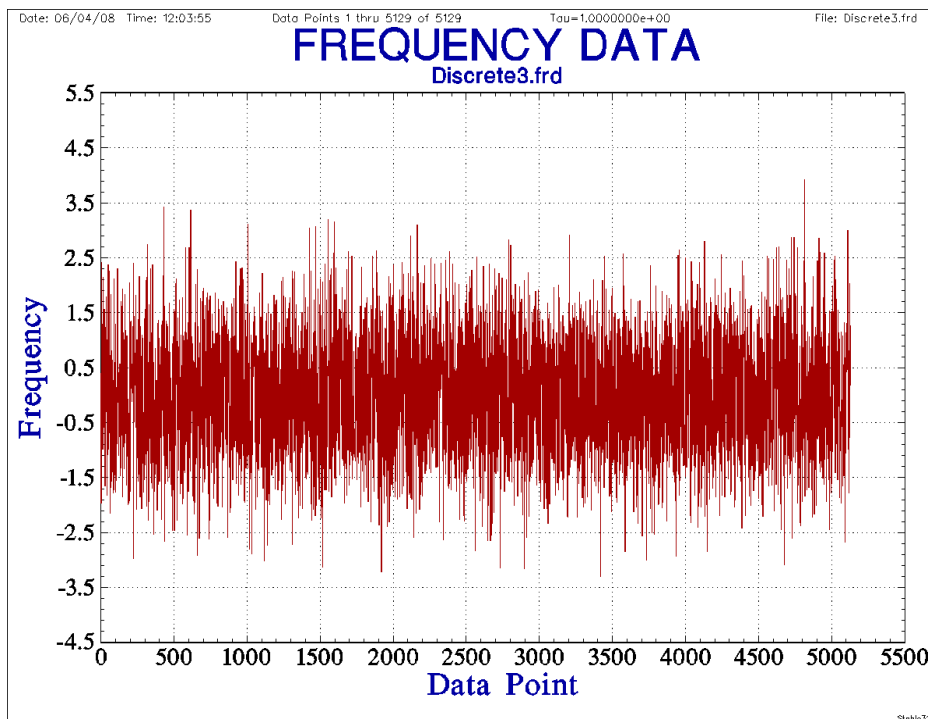


Figure 12. Corrected Frequency Data

And the time domain stability is now as expected for only the white FM noise:

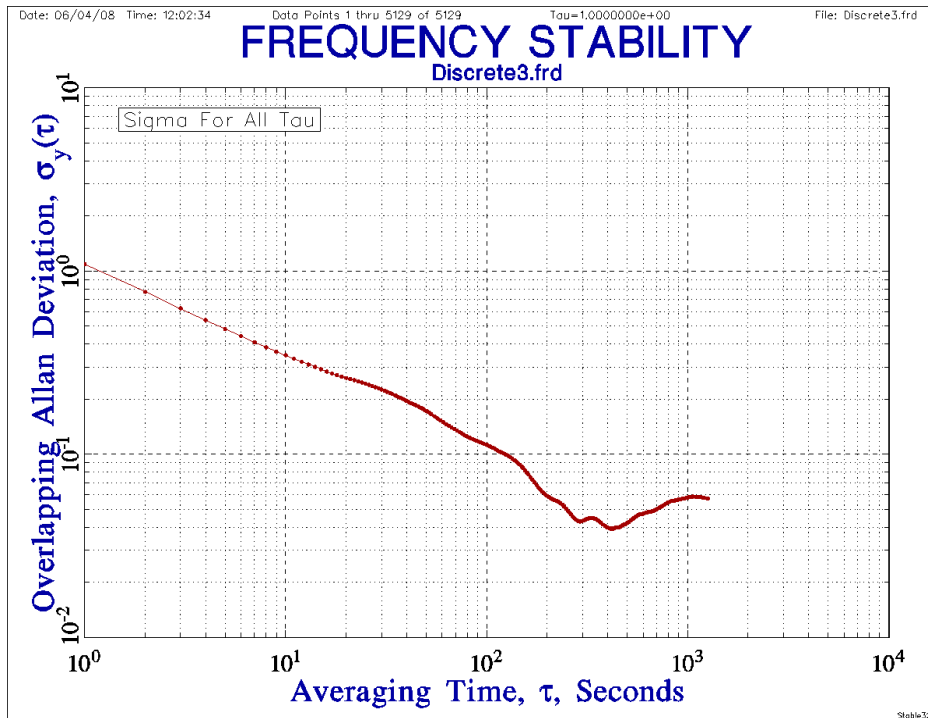


Figure 13. Allan Deviation Plot of Corrected Data

As a final example, consider the 5130-point, $\tau = 1$ set of simulated frequency data shown in Figure 14 that has $\sigma(1) = 1.0$ white FM noise, $D = 2e-3$ linear frequency drift and a single sinusoidal component of amplitude 1.0 and period 100τ , as listed in simulation parameters of Figure 15.

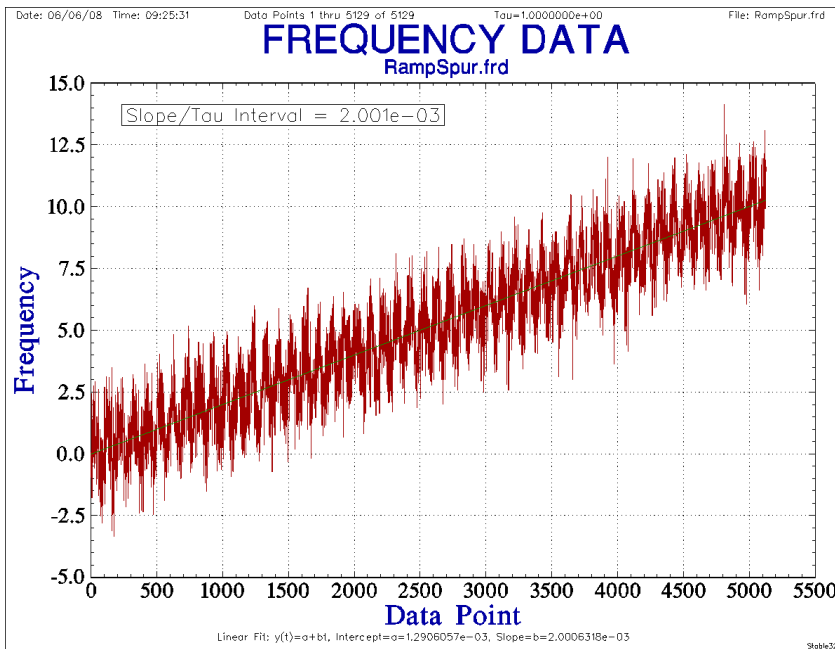


Figure 14. Simulated Frequency Data

```
Power-Law Noise Generation:
Points:
  Num=5130
  Tau=1.00000e+00
Noise Parameters:
  RW FM=0.00000e+00
  F FM=0.00000e+00
  W FM=1.00000e+00
  F PM=0.00000e+00
  W PM=0.00000e+00
Fractional Freq Parameters:
  Offset=0.00000e+00
  Drift/Tau=2.00000e-03
  Sine=1.00000e+00
  Period=1.00000e+02
```

Figure 15. Simulation Parameters

The noise, drift and periodic interference are all apparent in the time domain record of Figure 14 and in the following PSD and stability plots.

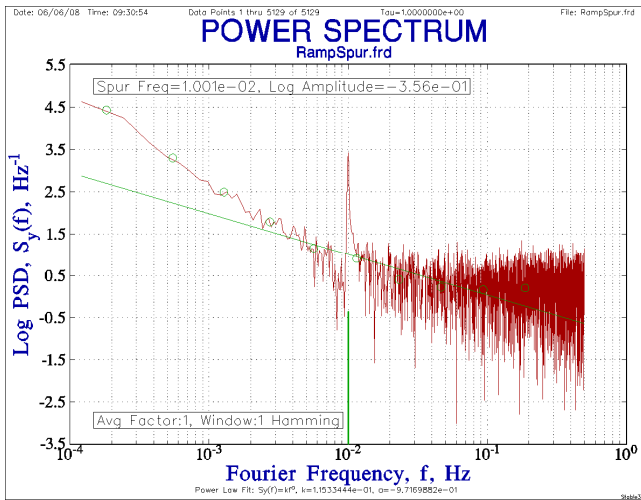


Figure 16. PSD of Simulated Data

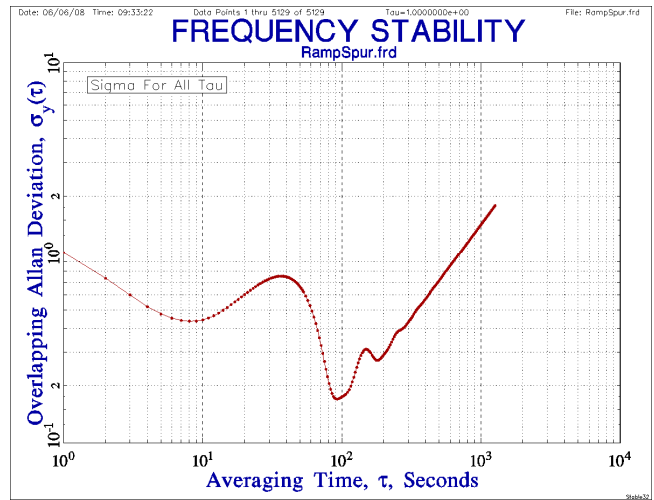


Figure 17. Stability Plot of Simulated Data

In the PSD plot of Figure 16, the 0.01 Hz spur is visible, as is the flat white FM noise at the higher Fourier frequencies and the rise of the PSD at the lower Fourier frequencies due to the frequency drift. In the stability plot of Figure 17, the ADEV is at the simulated $\sigma(1)=1.0$ level at small τ , but shows the periodic interference at medium τ and has a slope = 1 rise at long τ due to the linear drift.

After spur removal, the same types of plot show that the discrete periodic component is gone, leaving the noise and drift.

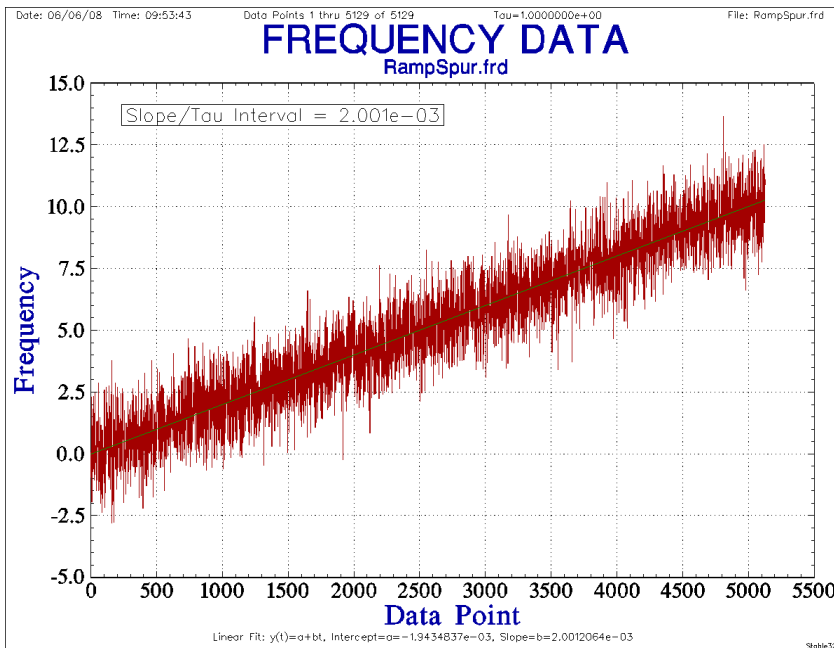


Figure 18. Data with Spur Removed

```
File: RampSpur.frd
PSD Type: Sy(f)
Avg Factor:1, Window:1 Hamming
Log Spur Threshold = 2.000e+00
(x100.00)
ENBW = 1.664e-04 Hz, Log NB Corr = -
3.78
PSD Discrete Spurs:
Spur   FFT   Spur           Discrete
#       Bin   Frequency      Amplitude
#       #     Hz              Log df/f
1       81    1.001e-02      -3.56e-01
```

Figure 19. Spur Analysis

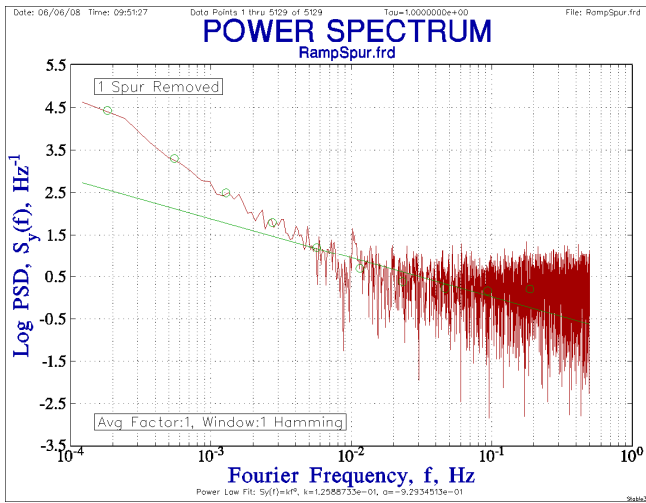


Figure 20. PSD with Spur Removed

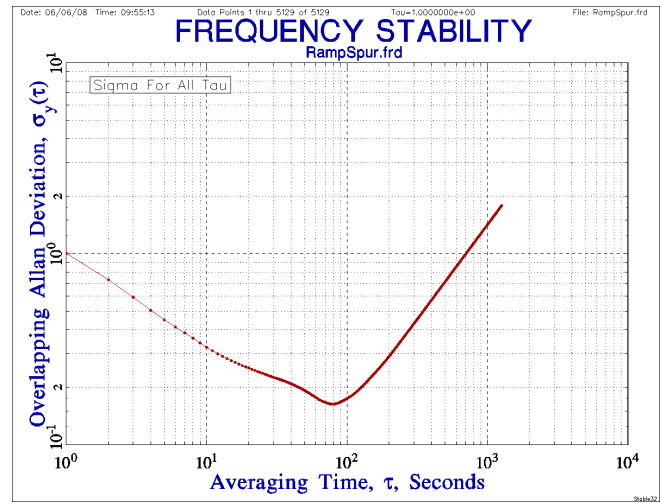


Figure 21. ADEV with Spur Removed

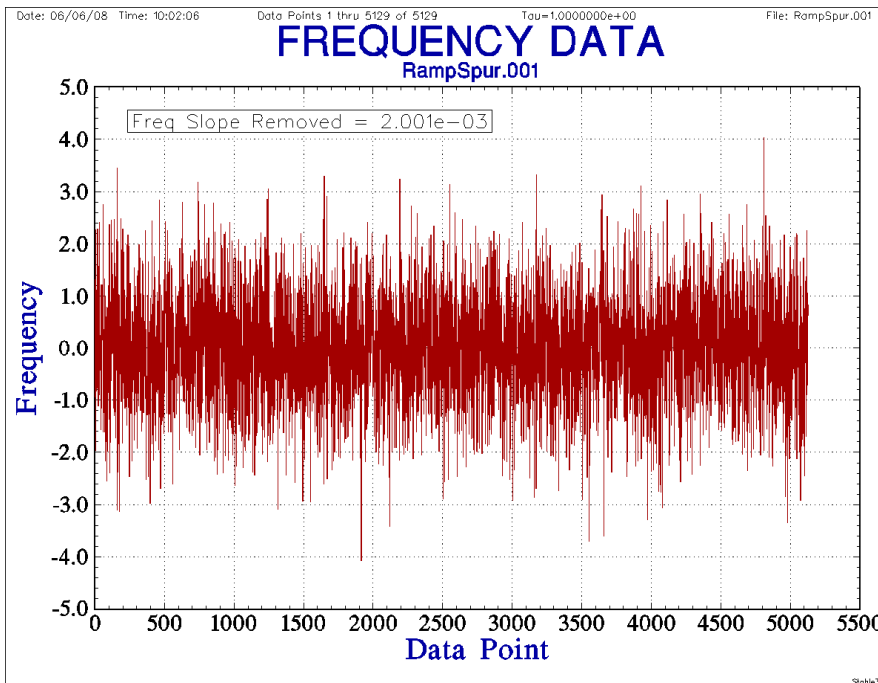


Figure 22. Data with Spur and Drift Removed

After linear drift removal, the plots show only white FM noise at the simulated level.

The data plot has no visible periodic component or drift, and the noise looks white.

The PSD plot is nearly flat at a log $S_y(f)$ level of 0, indicating white FM noise at the simulated level without any significant periodic component above the 20 dB spur threshold and PSD variance.

The ADEV plot shows the expected $\sigma(1)$ and $\tau^{-1/2}$ slope.

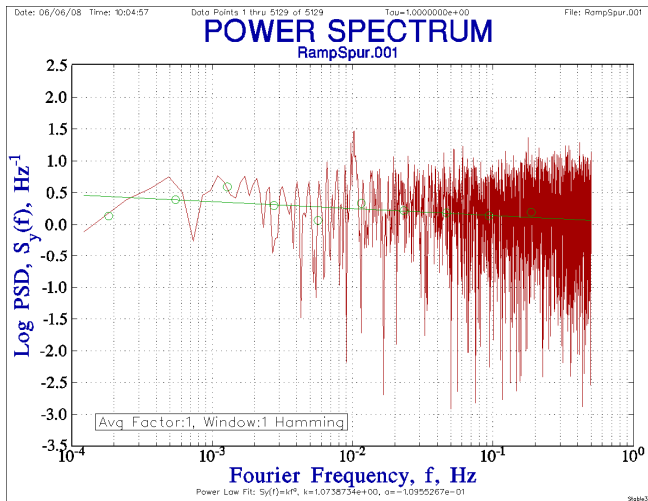


Figure 23. PSD with Spur and Drift Removed

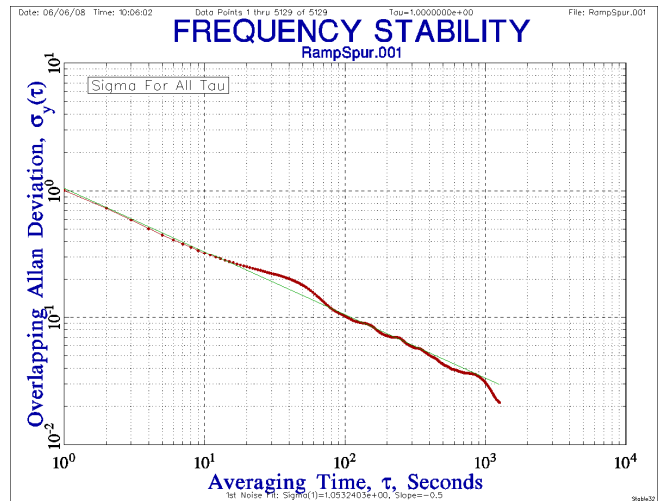


Figure 24. ADEV with Spur and Drift Removed

Judgment should always be applied when preprocessing frequency stability data before performing a noise analysis, but it is common to do so, especially by removing deterministic frequency drift. The Stable32 spur removal function adds the capability of doing the same for periodic interference without significantly affecting the underlying noise. As for any such data manipulation, the preprocessing methodology should be reported along with the analysis results.