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Correlating a narrow-bandwidth signal with DiFX

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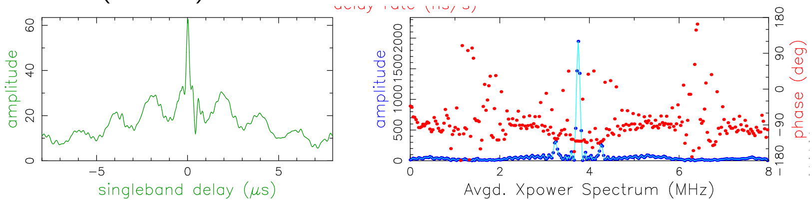
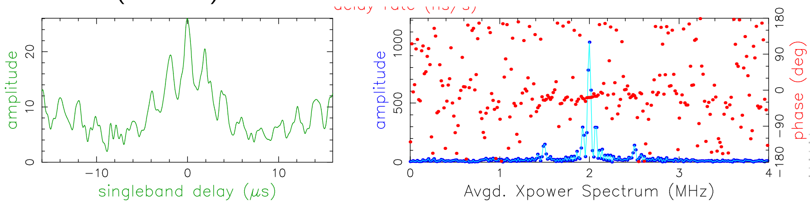
Example Fourfit plots from OCEL sessions

OCEL 1 (rd1405)



OCEL 12 (rd1613)



Introduction

- OCEL sessions
  - All recorded with 1-bit-sampling.
  - How to fringe-fit?
- DOR tones
  - are broader than just one channel in a subband.
  - These broad tones show clear phase relationships.
- Questions:
  1. Are the tones articificially broadened by 1-bit-sampling?
  2. Are phase-relationships artifacts of correlating quantization noise?
  3. How much of the data is real and can be used for fringe-fitting?
- Method: Generate simulated time series, with and without 1-bit-sampling, and output cross-power-spectra.

Input	Configuration: Spectrum and/or DOR tones
↓ Time series	Generate two time series with spectral characteristics provided by input configuration and delay τ_g
↓ Quantization	On: 1-bit-sampling, Off: 64-bit-sampling
↓ Fourier transform	Same spectral resolution as input spectrum
↓ Cross-power-spectrum	Output

Input

1. Spectrum
   - Number of spectral points N,
   - Amplitude A_i and phase ϕ_i for each frequency.
2. DOR tones
   - Signal power P_{T},
   - Carrier frequency f_{c},
   - Tone frequencies f_1, f_2, and amplitudes θ_1, θ_2,
   - Amplitude θ of the data channel.
3. Noise
   - Amplitude of uncorrelated white noise component.
4. Group delay
   - The second time series is delayed by τ_{g} with respect to the first.

Generate a signal in the time domain:

$$
\begin{aligned}
s_1(t) &= n_1(t) + \sum_{i=1}^{N} A_i \sin(2\pi f_i t + \phi_i) + s_{\mathrm{DOR}}(t) \\
s_2(t) &= n_2(t) + \sum_{i=1}^{N} A_i \sin(2\pi f_i (t - \tau_{\mathrm{g}}) + \phi_i) + s_{\mathrm{DOR}}(t - \tau_{\mathrm{g}})
\end{aligned}
$$

with

N	Number of spectral points
A_i	Amplitude
f_i	Frequency
ϕ_i	Phase
$n_{1,2}$	White noise (uncorrelated)
τ_{g}	Group delay
s_{DOR}	DOR signal (next slide)

Generation of Time Series

The DOR signal:

$$s_{\mathrm{DOR}}(t) = \sqrt{2P_{\mathrm{T}}}\sin[\underbrace{2\pi f_{\mathrm{c}} t}_{\text{Carrier}} + \underbrace{\theta_1 \sin 2\pi f_1 t}_{\text{Tone 1}} + \underbrace{\theta_2 \sin 2\pi f_2 t}_{\text{Tone 2}} + \underbrace{\theta d(t)}_{\text{Data}}]$$

with

P_{T}	Power of the signal
f_{c}	Carrier frequency
θ_1	Amplitude tone 1
f_1	Frequency tone 1
θ_2	Amplitude tone 2
f_2	Frequency tone 2
θ	Amplitude of data channel
d	Data channel (currently implemented as *correlated* noise)

DOR tones and data phase-modulated on the carrier frequency.

Without: Represent $s(t)$ by a 64-bit floating point number.

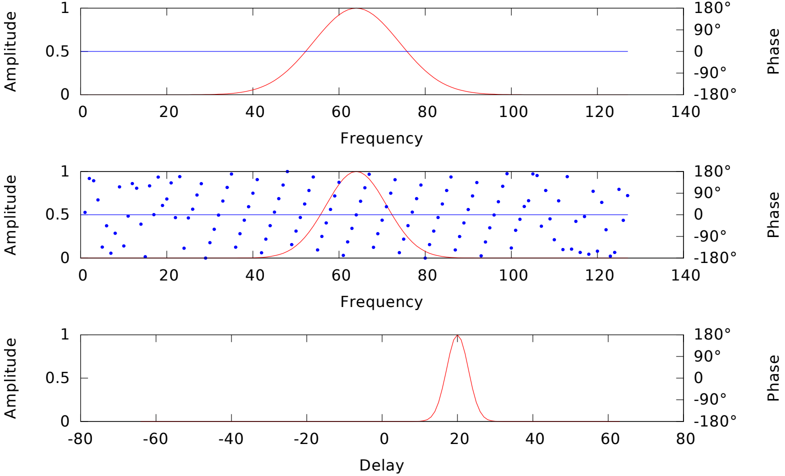
1-bit-sampling:

$$s_{1\mathrm{bit}}(t) = \begin{cases} +1 & \text{if } s(t) > 0, \\ -1 & \text{if } s(t) \leq 0. \end{cases}$$

Example 1: Gaussian

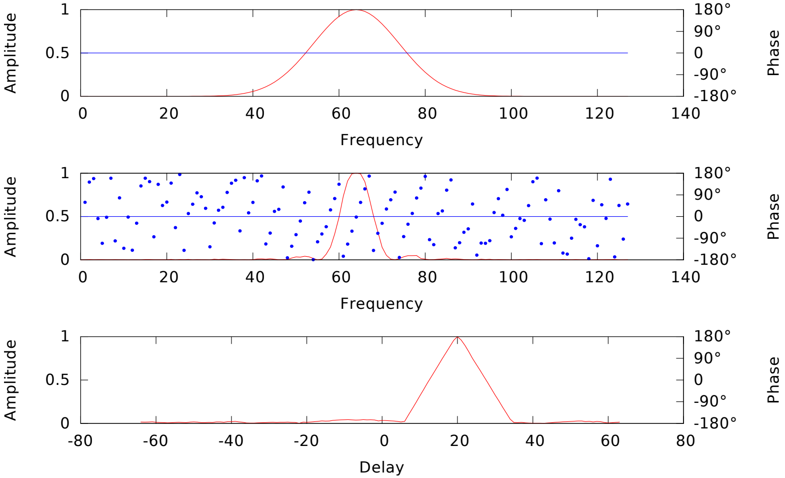
$$A_i = \exp\left(-\frac{1}{2}\frac{(i - f_0)^2}{\sigma^2}\right)$$

- Number of spectral channels $N = 128$,
- Tone in the center of the band $f_0 = 64$,
- Vary σ from 10 to 1,
- Noise amplitude 0.10,
- $\tau_\mathrm{g} = 20$.



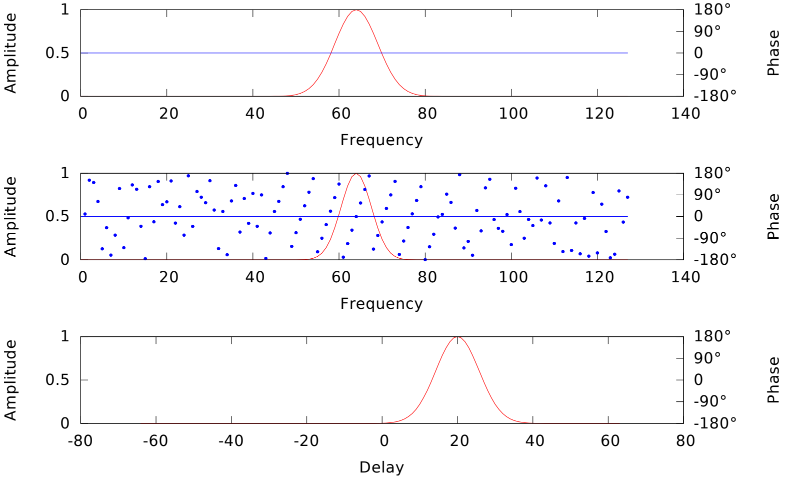
$\sigma = 10$, no quantization.

Results 1: Gaussian

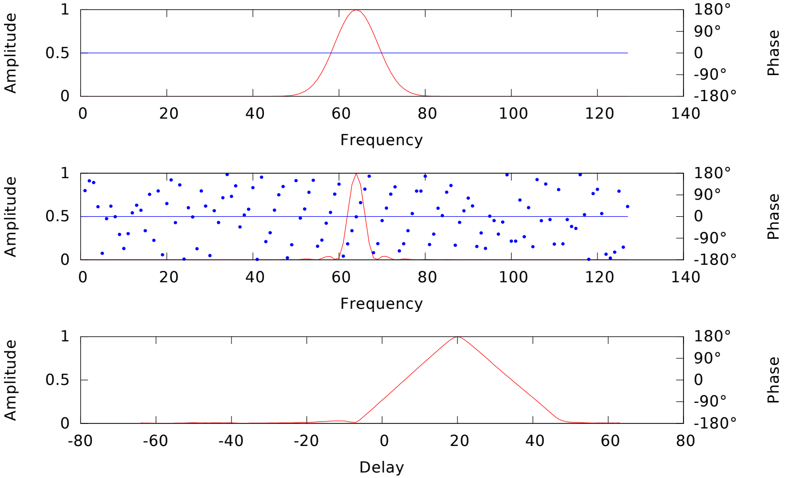


$\sigma = 10$, 1-bit-sampling.

Results 1: Gaussian

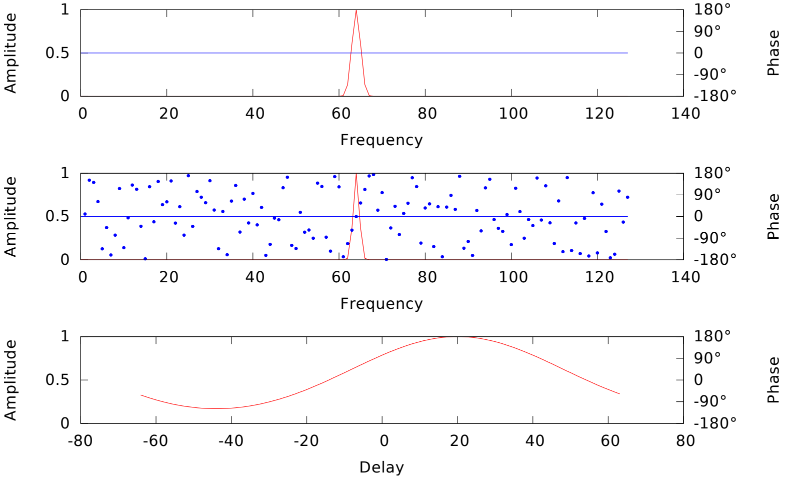


$\sigma = 5$, no quantization.



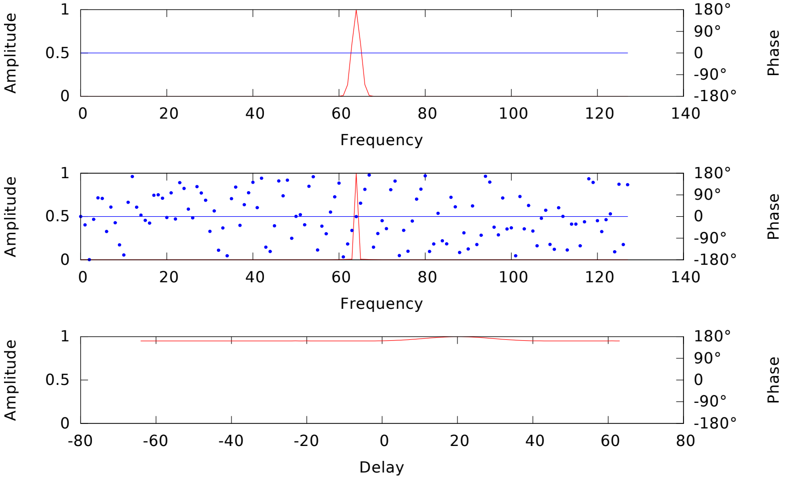
$\sigma = 5$, 1-bit-sampling.

Results 1: Gaussian



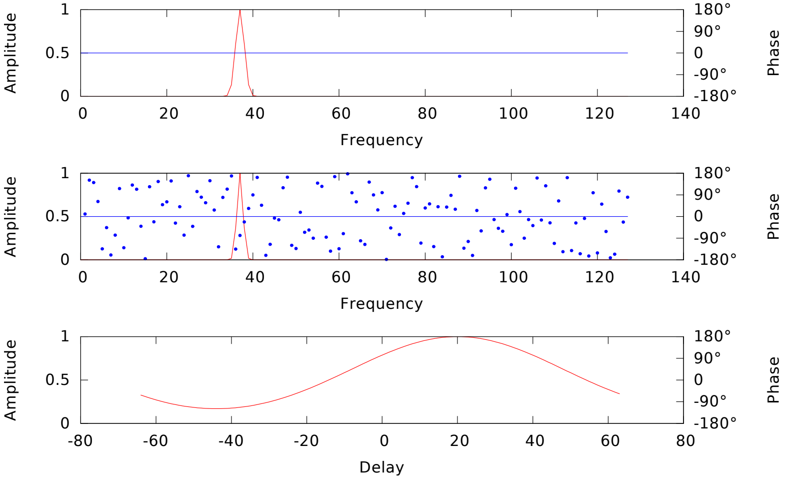
$\sigma = 1$, no quantization.

Results 1: Gaussian



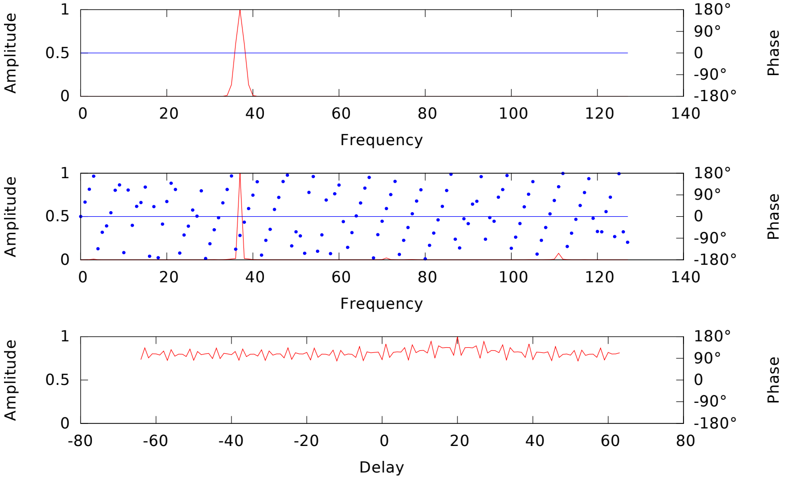
$\sigma = 1$, 1-bit-sampling.

Results 1: Gaussian



$\sigma = 1$, $f_0 = 37$, no quantization.

Results 1: Gaussian



$\sigma = 1$, $f_0 = 37$, 1-bit-sampling.

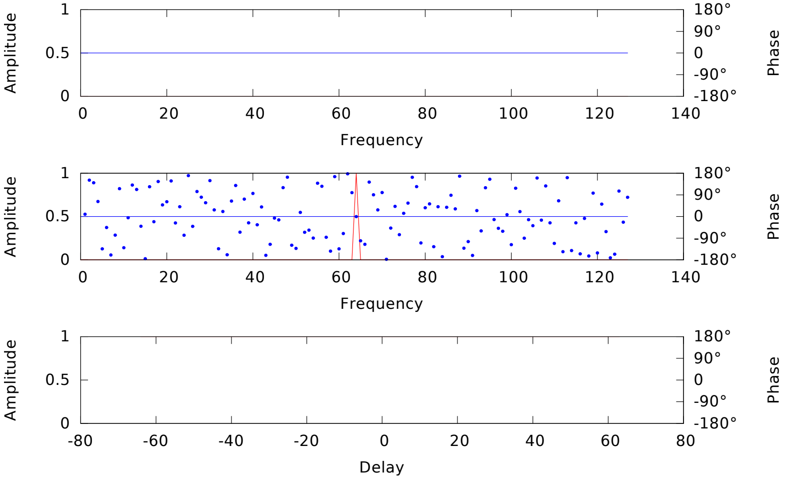
Example 2: DOR tone
Configuration:

$$\begin{aligned} P_\mathrm{T} &= 1 \\ \theta &= 0 \\ \theta_1 &= 0 \\ \theta_2 &= 0 \end{aligned}$$

Only the carrier, everything else switched off, vary f_c.

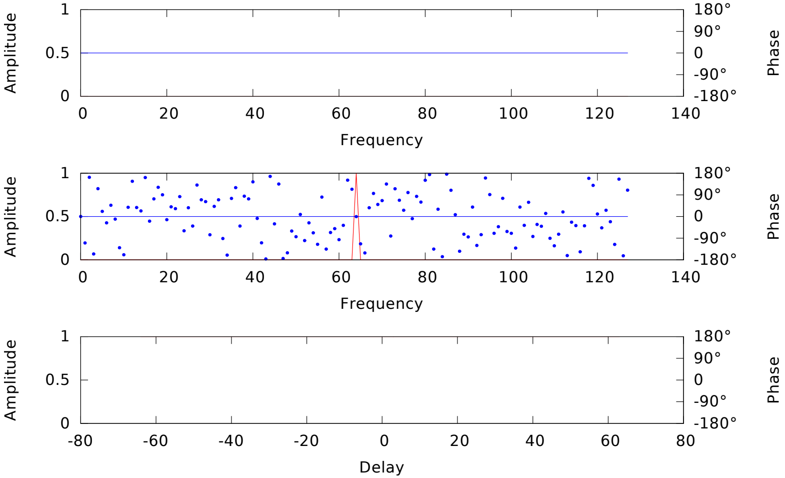
$$\tau_\mathrm{g} = 20$$

Results 2: DOR tone



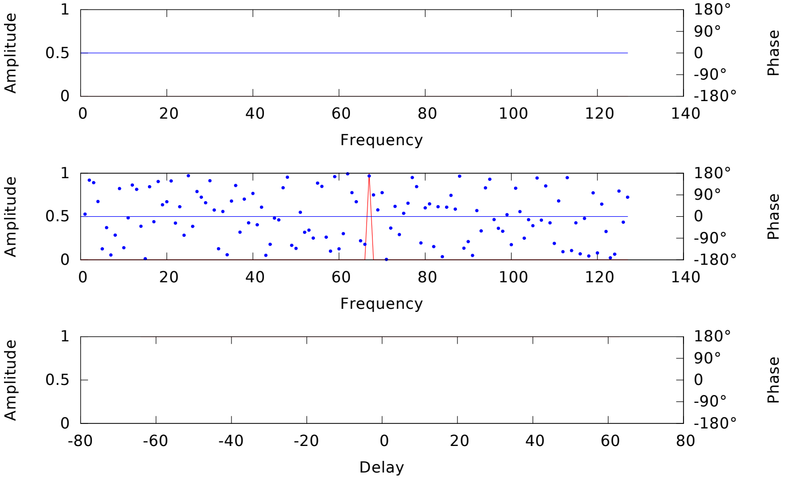
$f_c = 64$, no quantization.

Results 2: DOR tone



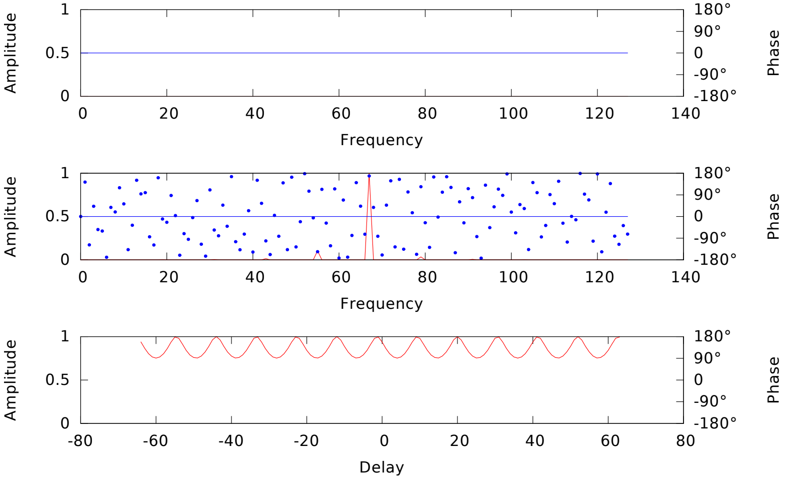
$f_c = 64$, 1-bit-sampling.

Results 2: DOR tone



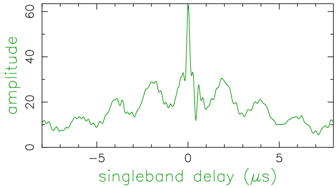
$f_c = 67$, no quantization.

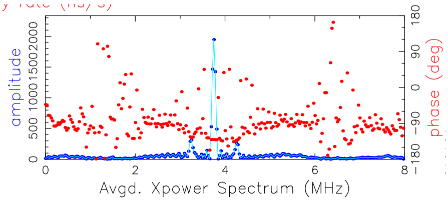
Results 2: DOR tone



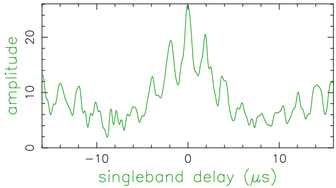
$f_c = 67$, 1-bit-sampling.

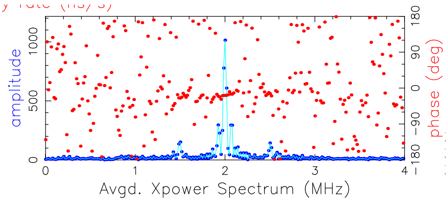
OCEL 1 (rd1405)





OCEL 12 (rd1613)





Conclusion and Outlook

1. 1-bit-sampling can affect the width of a tone.
    - Usually gets narrower in frequency.
    - The rest of the power is distributed over the band.
2. The way that the tone is affected depends on the configuration.
    - Tones at the center of a band are least affected.
    - Tones offset from the center create artifacts.
3. Phase at the peak of the tone mostly unaffected so far.

Thank you!