RFI Mitigation

Vadym Paznukhov
University of Massachusetts Lowell
Environmental, Earth, & Atmospheric Sciences Department
Center for Atmospheric Research

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New opportunities provided by DPS-4D system

More flexible control over the DPS operational mode settings and availability of the raw data make possible the following :

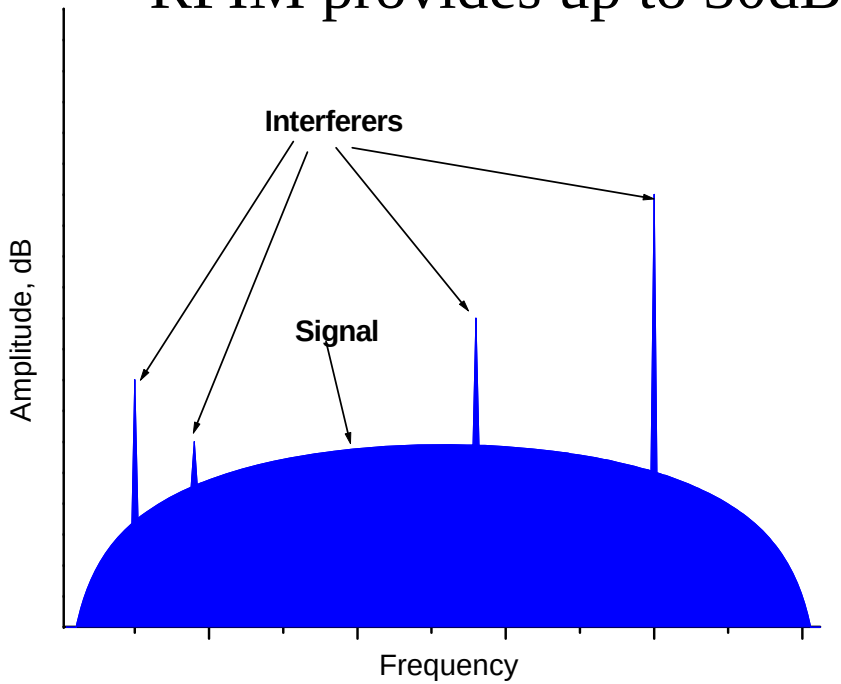
- Implementing advanced signal processing algorithm aimed at improving system performance. One such technique RFIM (Radio Frequency Interference Mitigation) has been successfully implemented.

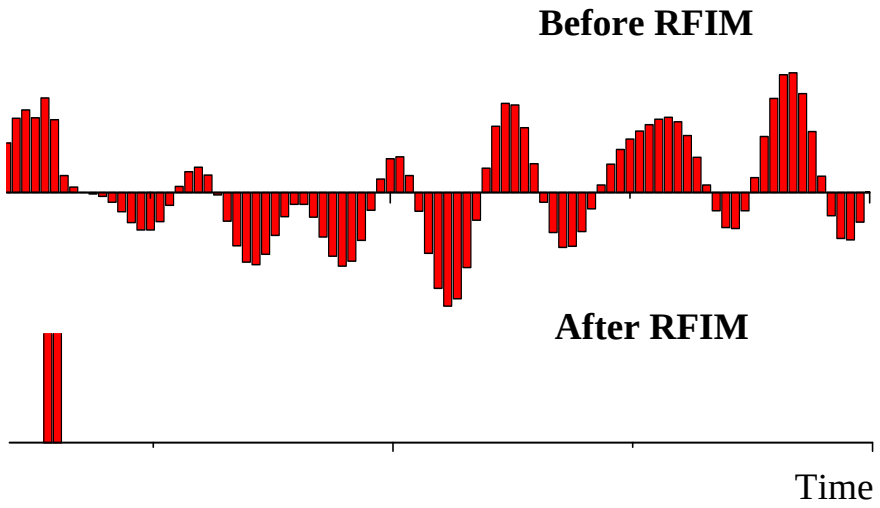
- Introducing new types of operational modes. Very short (<1min) as well as very long ionograms (providing sufficient Doppler resolution for velocity calculation) are now available. Precision group height measurements are now implemented into routine ionospheric sounding.

- Designing signal-specific frequency characteristics of the system, crucial for reception of “external” signals: transmitters of opportunity, HAARP transmission, etc.,

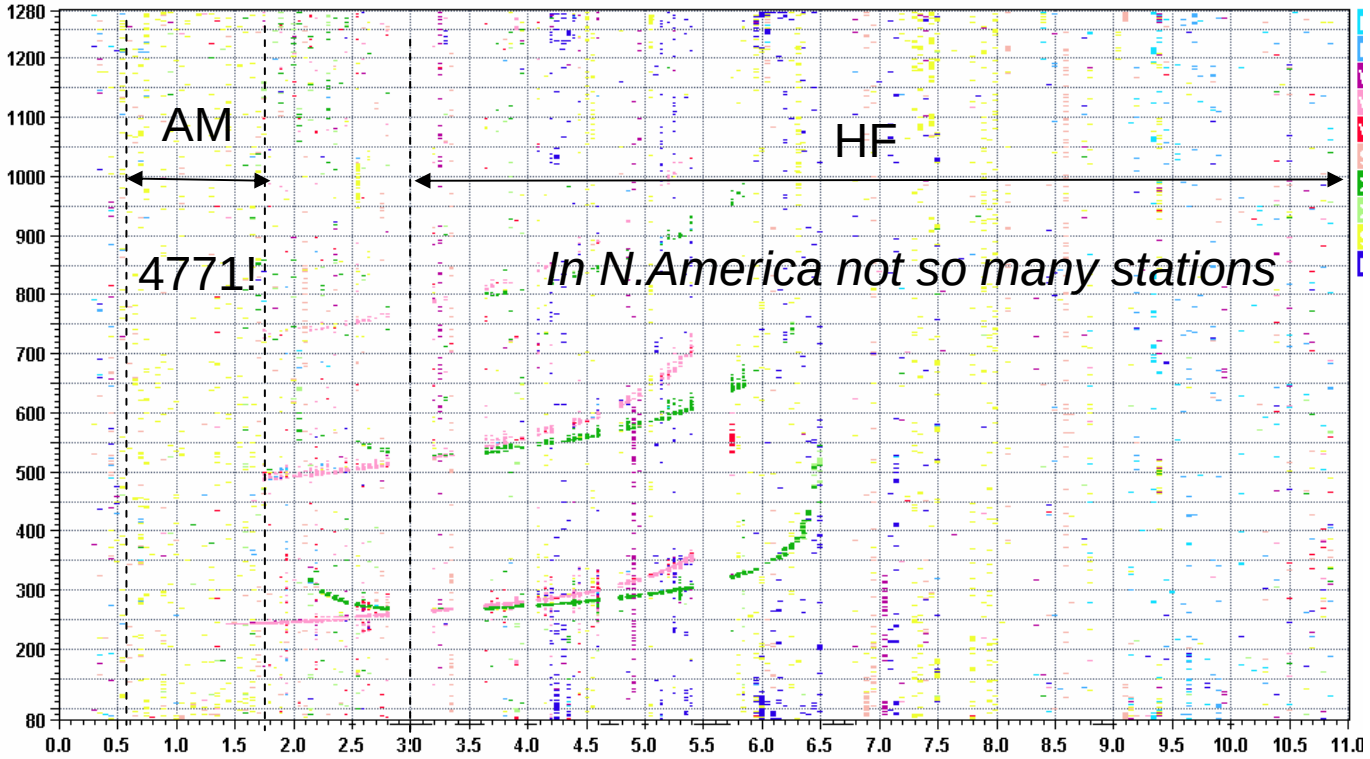
RFI Mitigation basics

- Idea by Dr. Klaus Bibl (patented)
- RFIM is removing interferer signals from the received signal
- Interferers are associated with broadcast station signals
- Removal is performed in time domain
- Complex spectral analysis is essential
- RFIM provides up to 30dB signal-to-noise ratio improvement



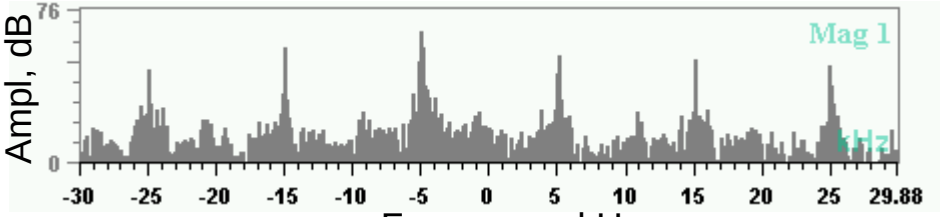


Interference

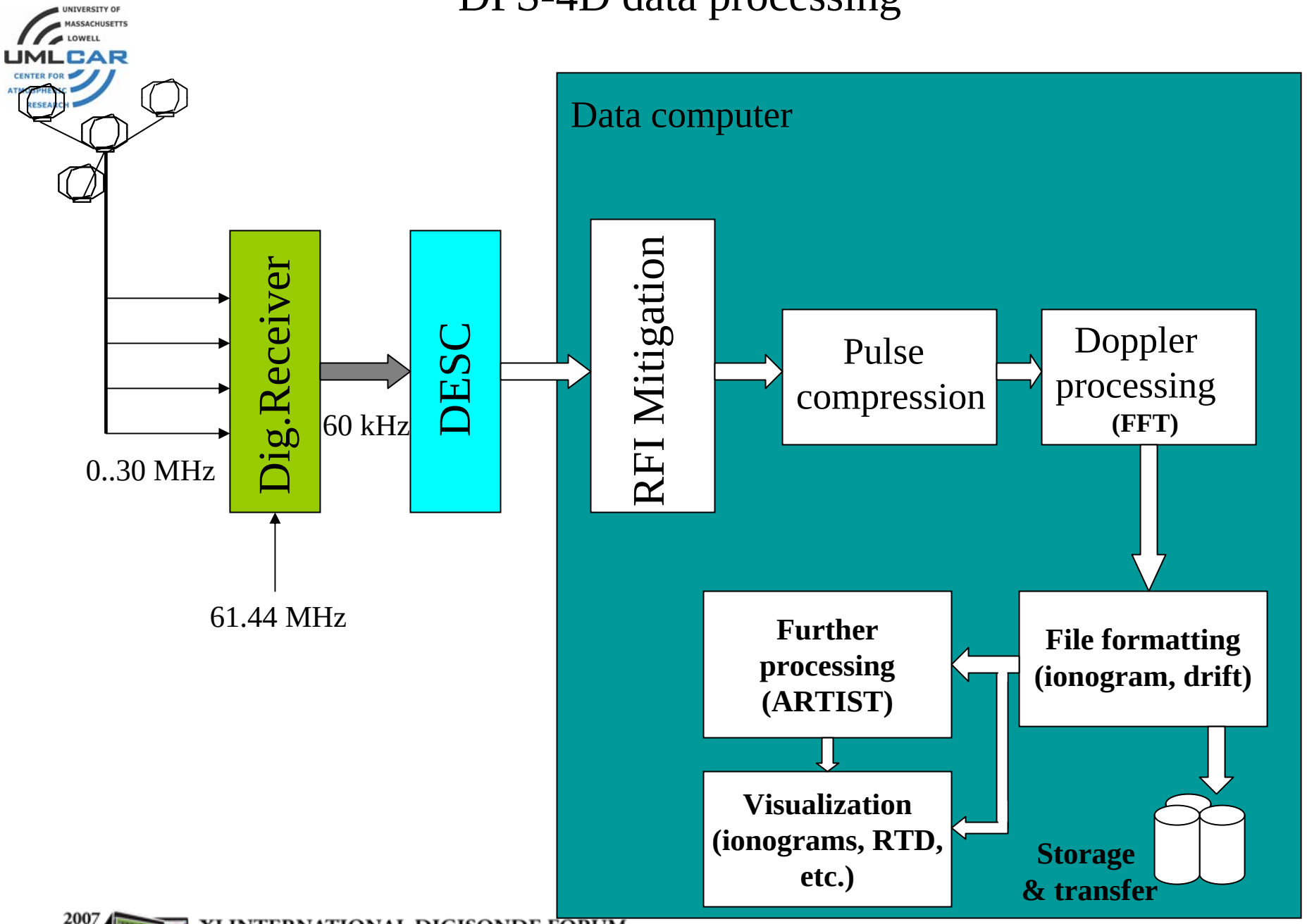


AM or Medium-wave range:
530 kHz to 1610/1710 kHz
4,771 broadcasting stations in USA, ~60 in MA
HF or Short-wave range
3 MHz to 30 MHz
~25 broadcasting stations in USA

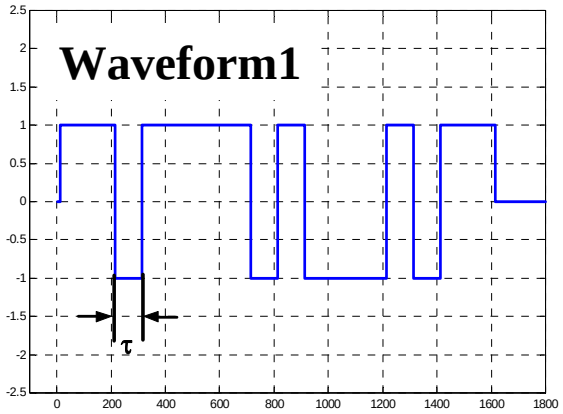
Millstone Hill, 1.6 MHz, 1830 LT

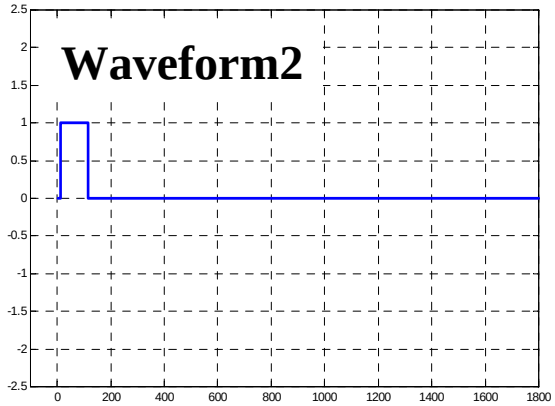


DPS-4D data processing

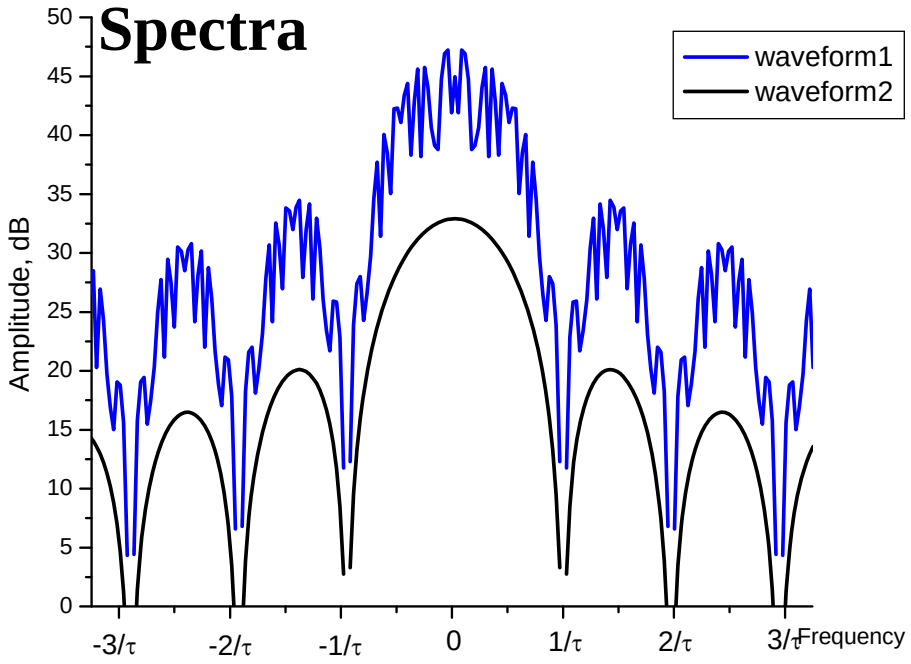


DPS waveforms in time and spectral domains





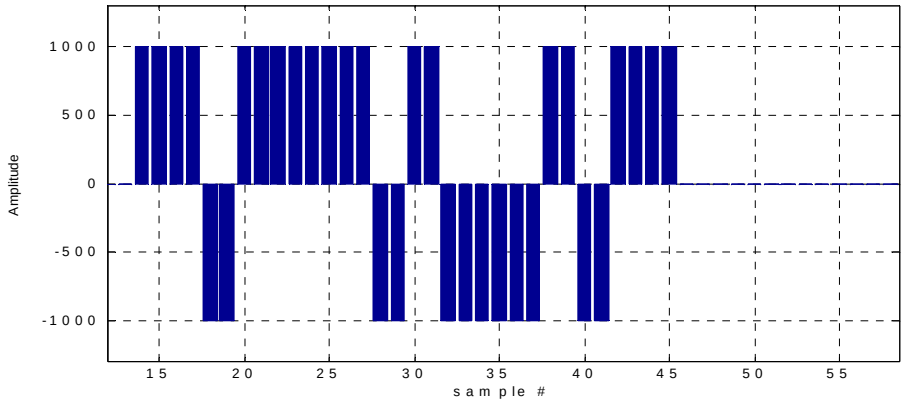
$\tau = 33.33\mu sec$



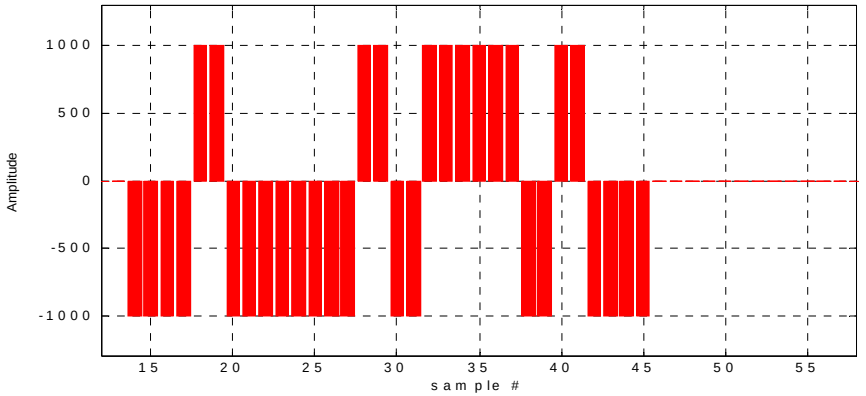
$\Delta f = 2/\tau = \pm 30$ kHz

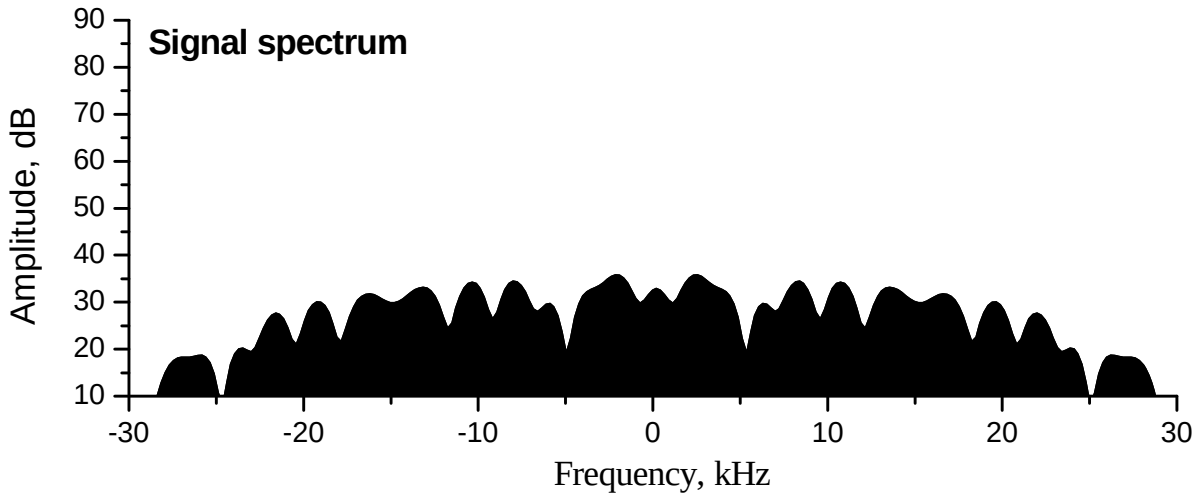
Digitized DPS-4D signal

“Real” samples

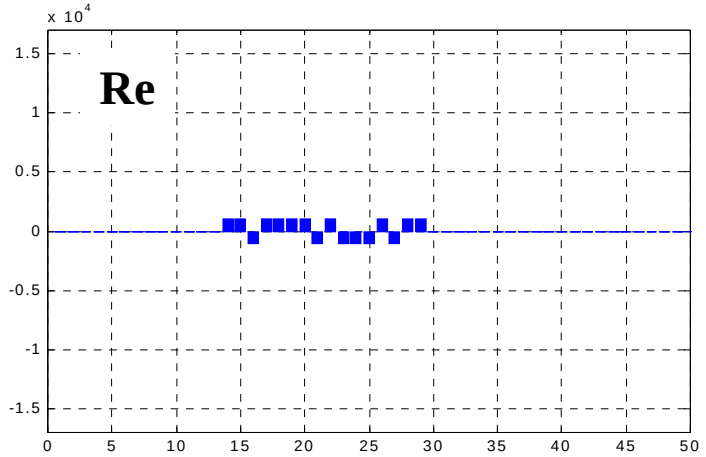


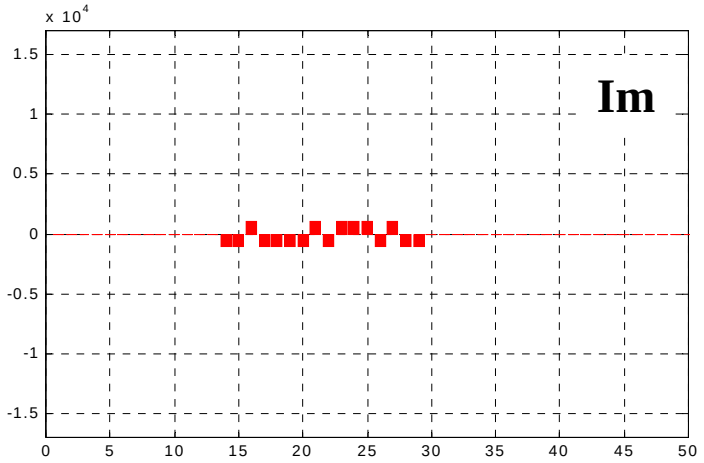
“Imag” samples

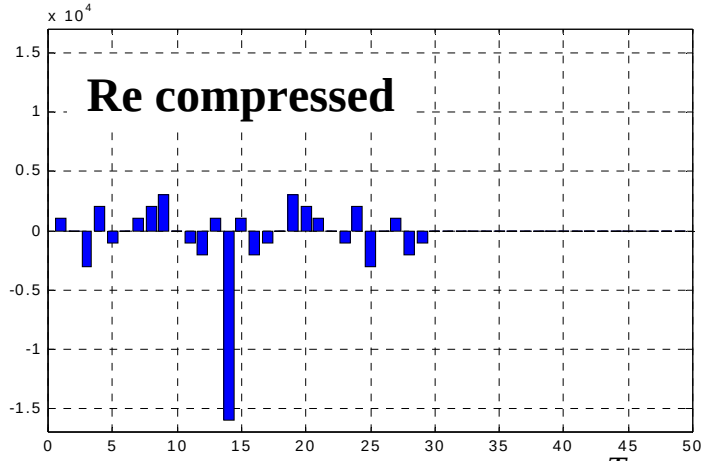


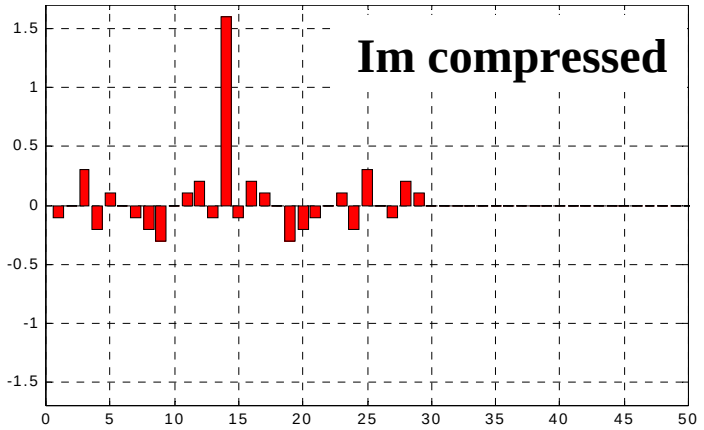


Pulse compression





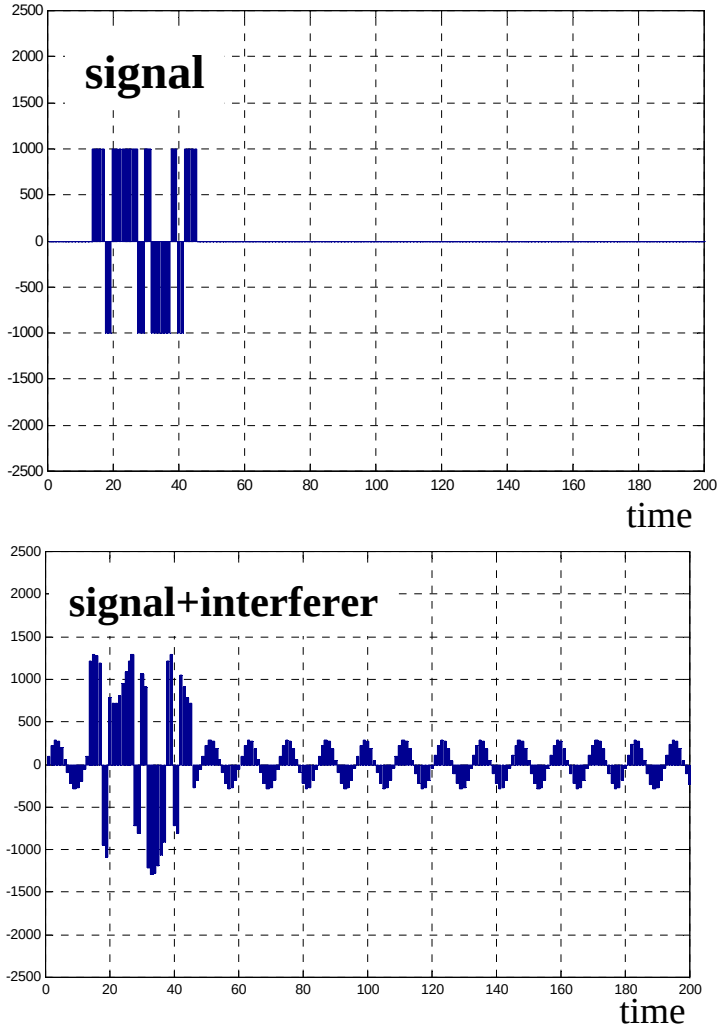


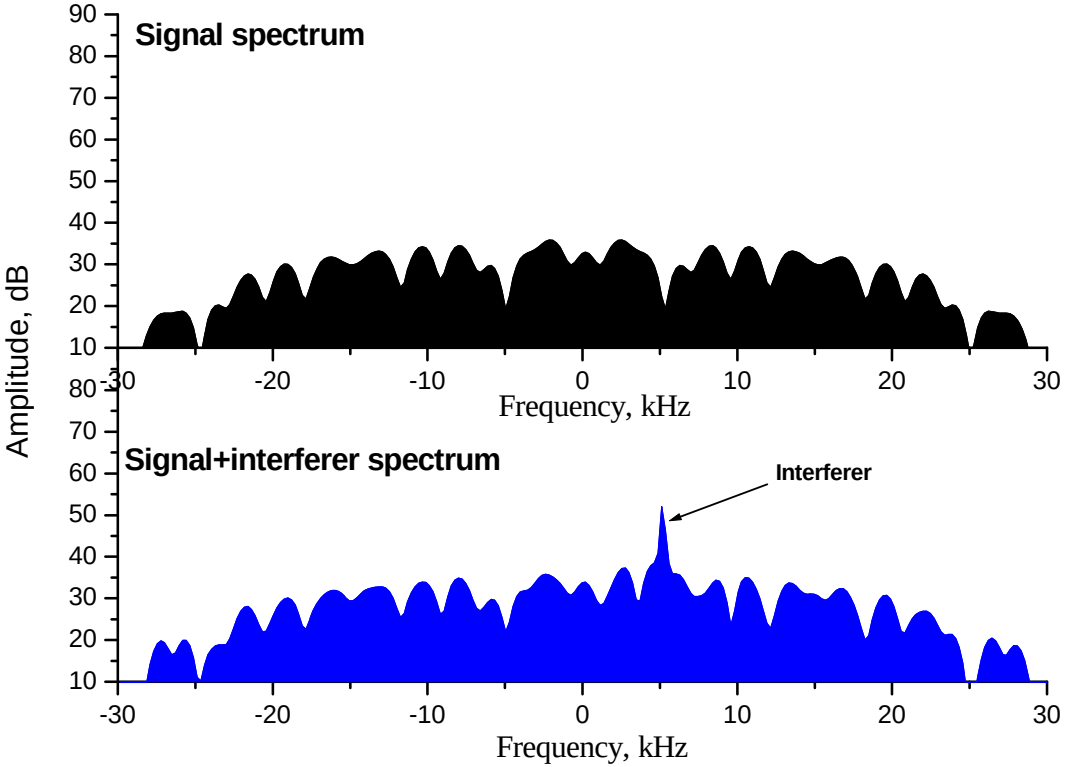


$$\mathrm{Re}[signal_{compr}(\tau)] = \int_0^T \mathrm{Re}[signal(t+\tau)] \cdot \mathrm{Re}[code(t)]dt$$

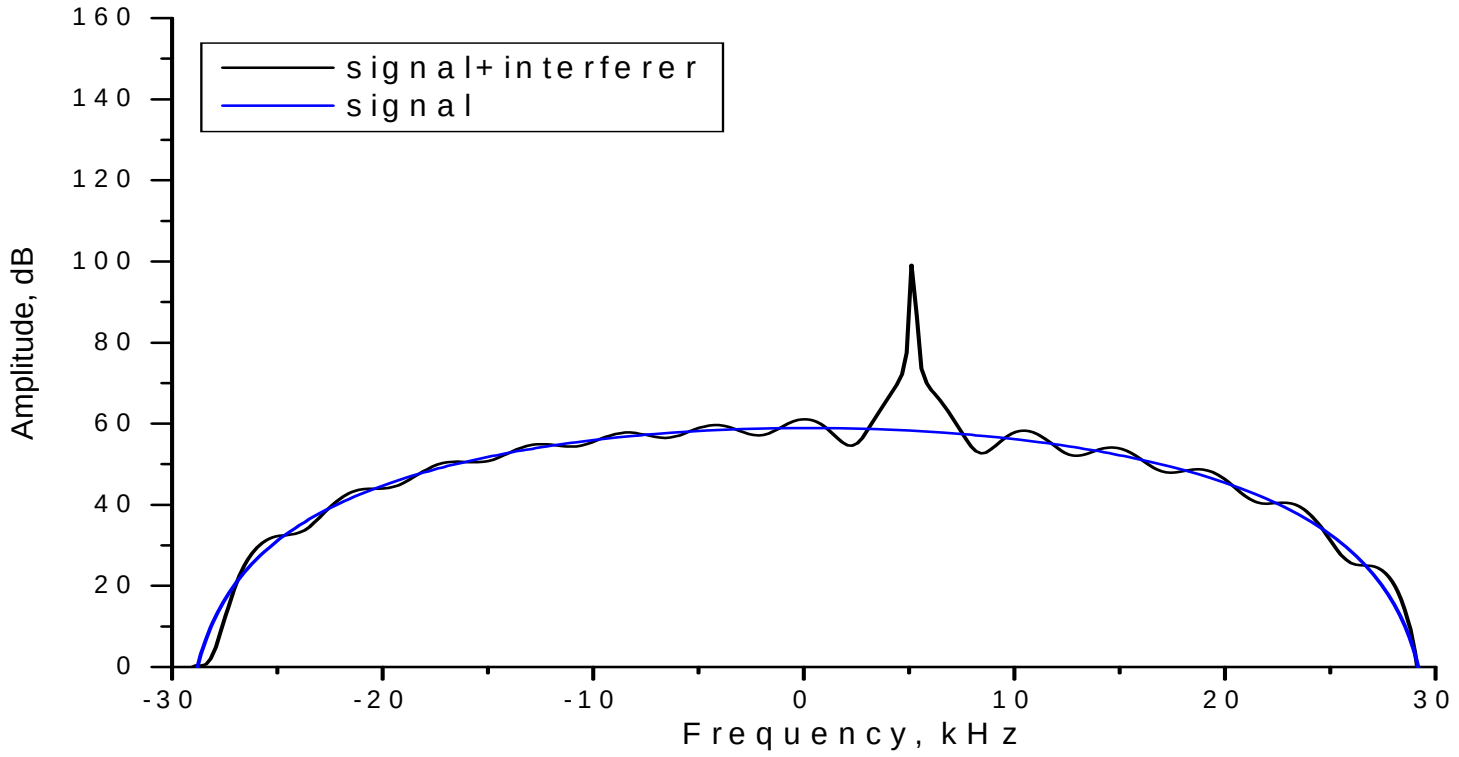
Compressing the pulse means calculating the convolution between received signal and the original waveform ("*code*")

Interferer effect





Interferer effect on signal spectrum

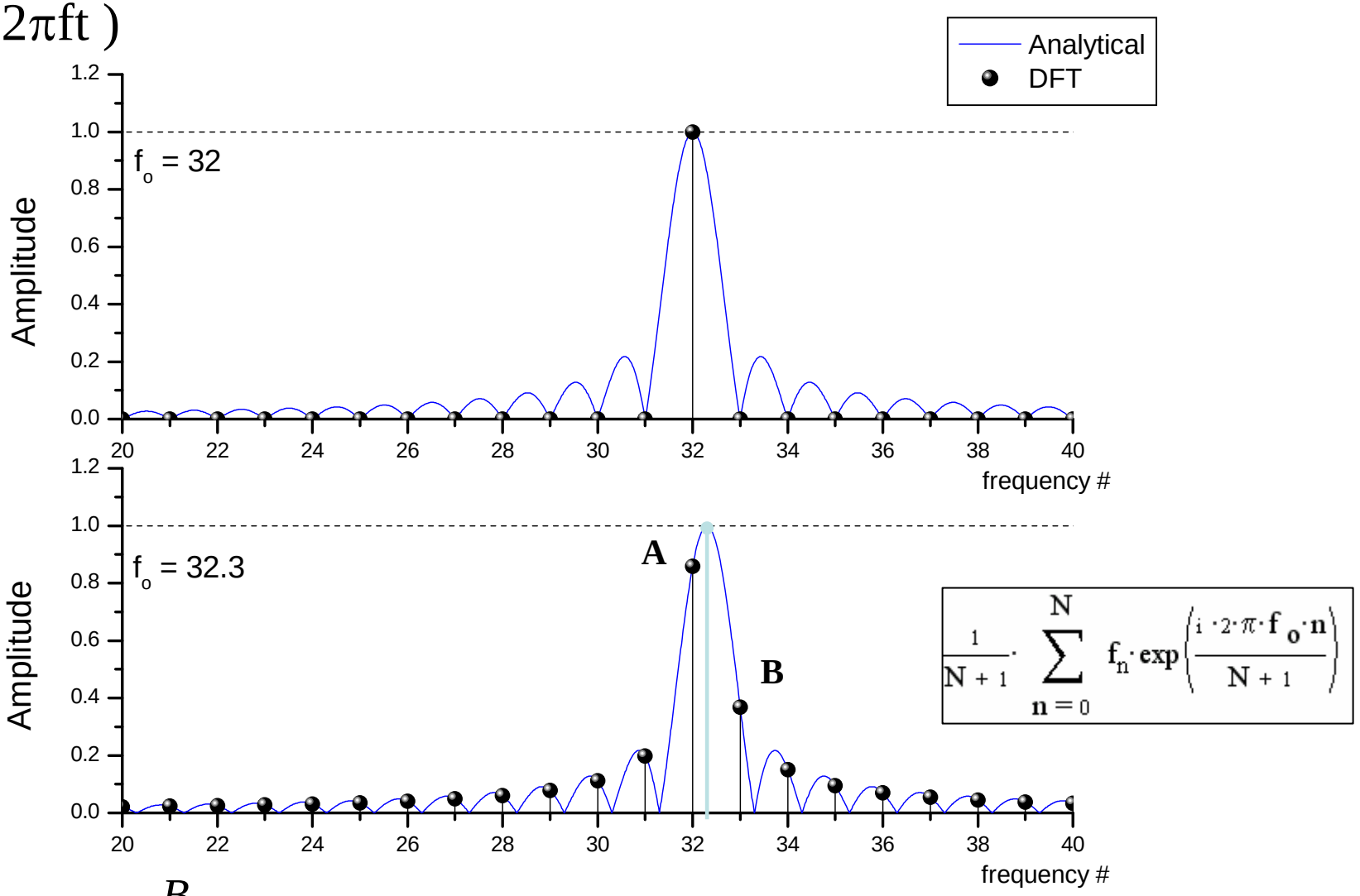


f_o = 5 kHz

Note: “short pulse” is used as a signal to emphasize the effect

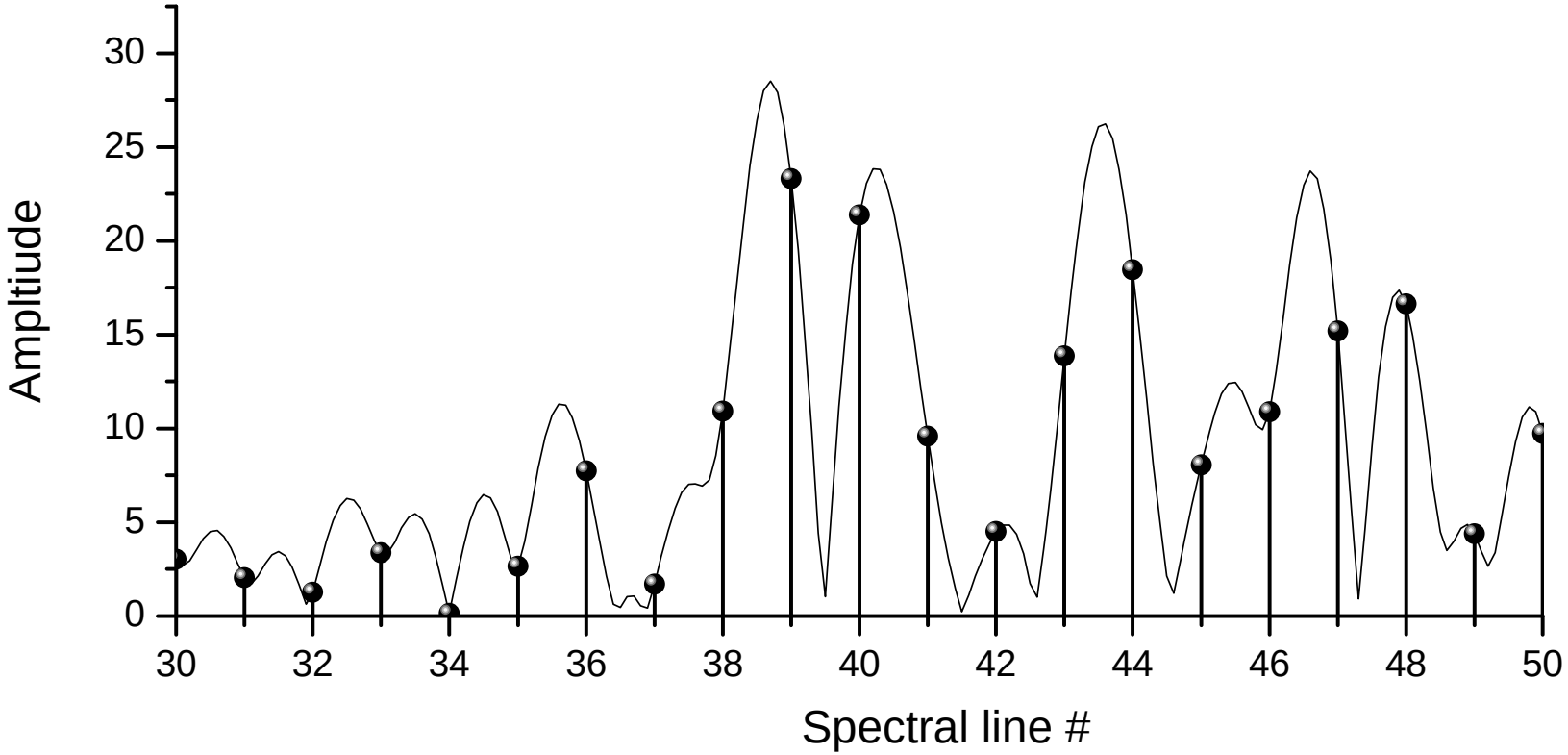
Modeled interferer spectrum

$\cos(2\pi ft)$

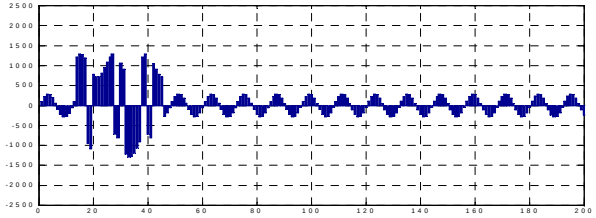


$$f_o = f_A + \frac{B}{A+B}$$

Real signal spectrum showing interferers



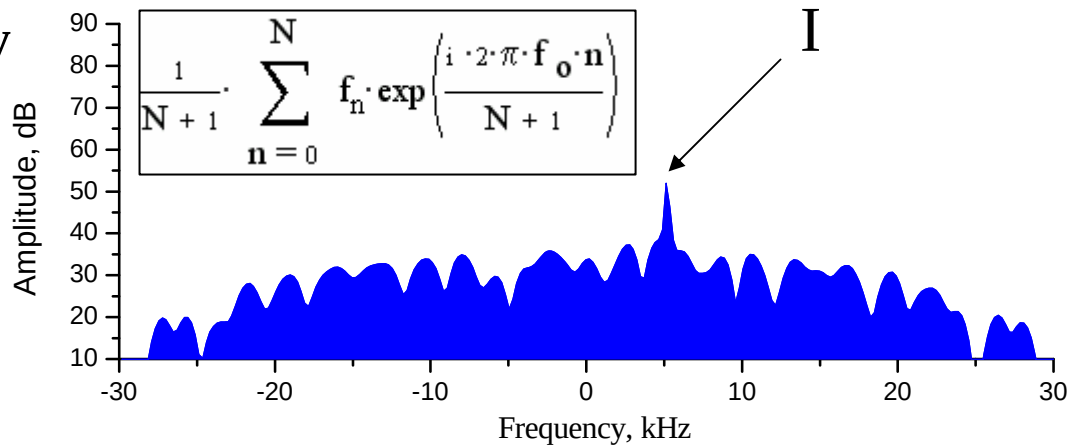
RFIM algorithm



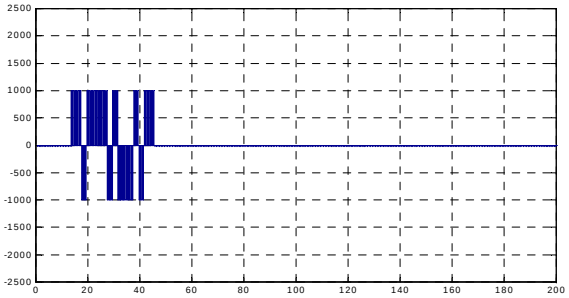
1. Take DFT of the signal. Find "peak" in the spectrum.

2. Determine exact frequency of the interferer.

$$f_o = f_A + \frac{B}{A+B}$$



3. Do "single line spectral analysis" to determine exact interferer amplitude and phase.

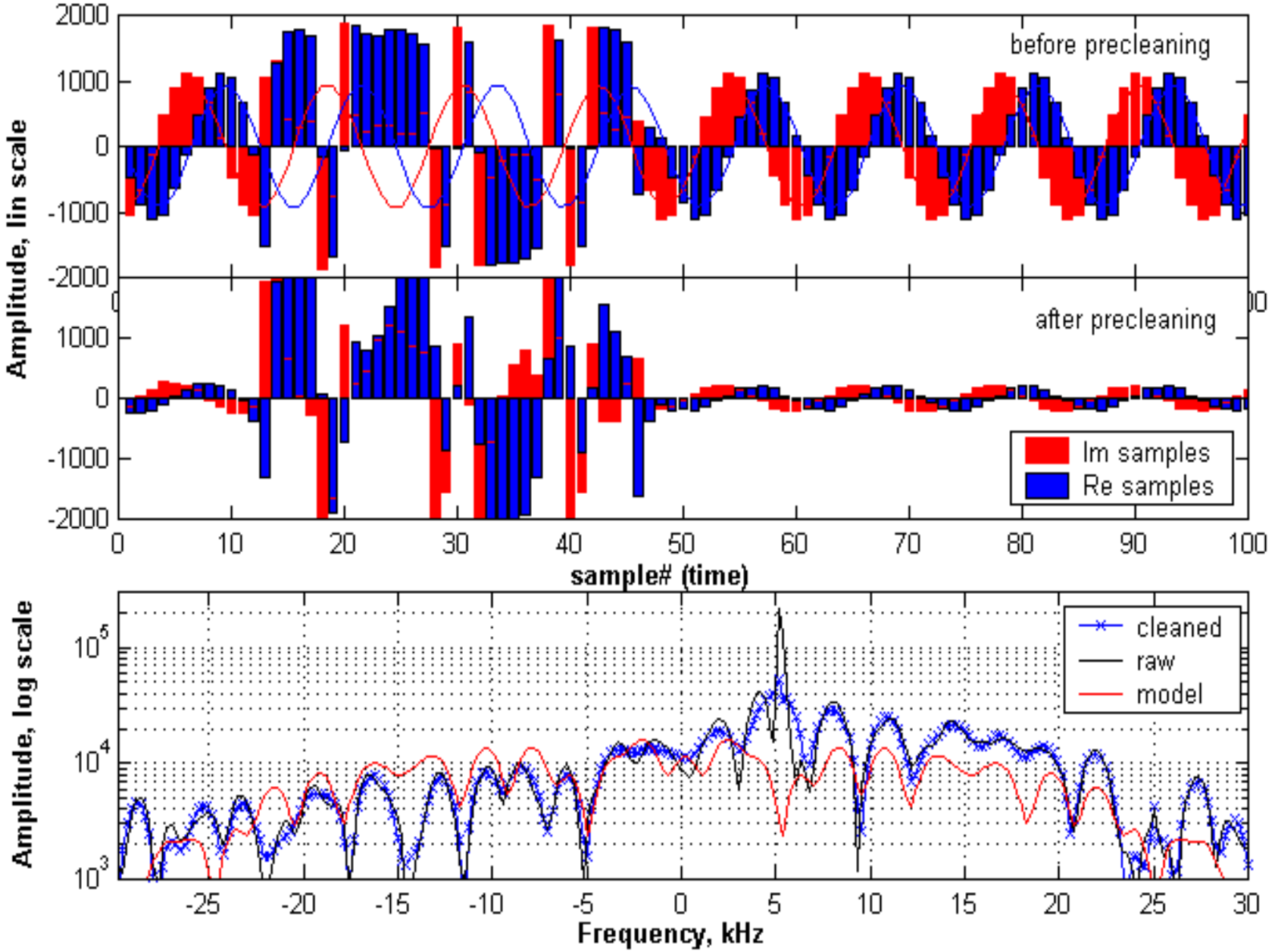


4. Subtract interferer in time domain.

5. Repeat steps 1-4 until happy or bored.
(no more peaks can be found)

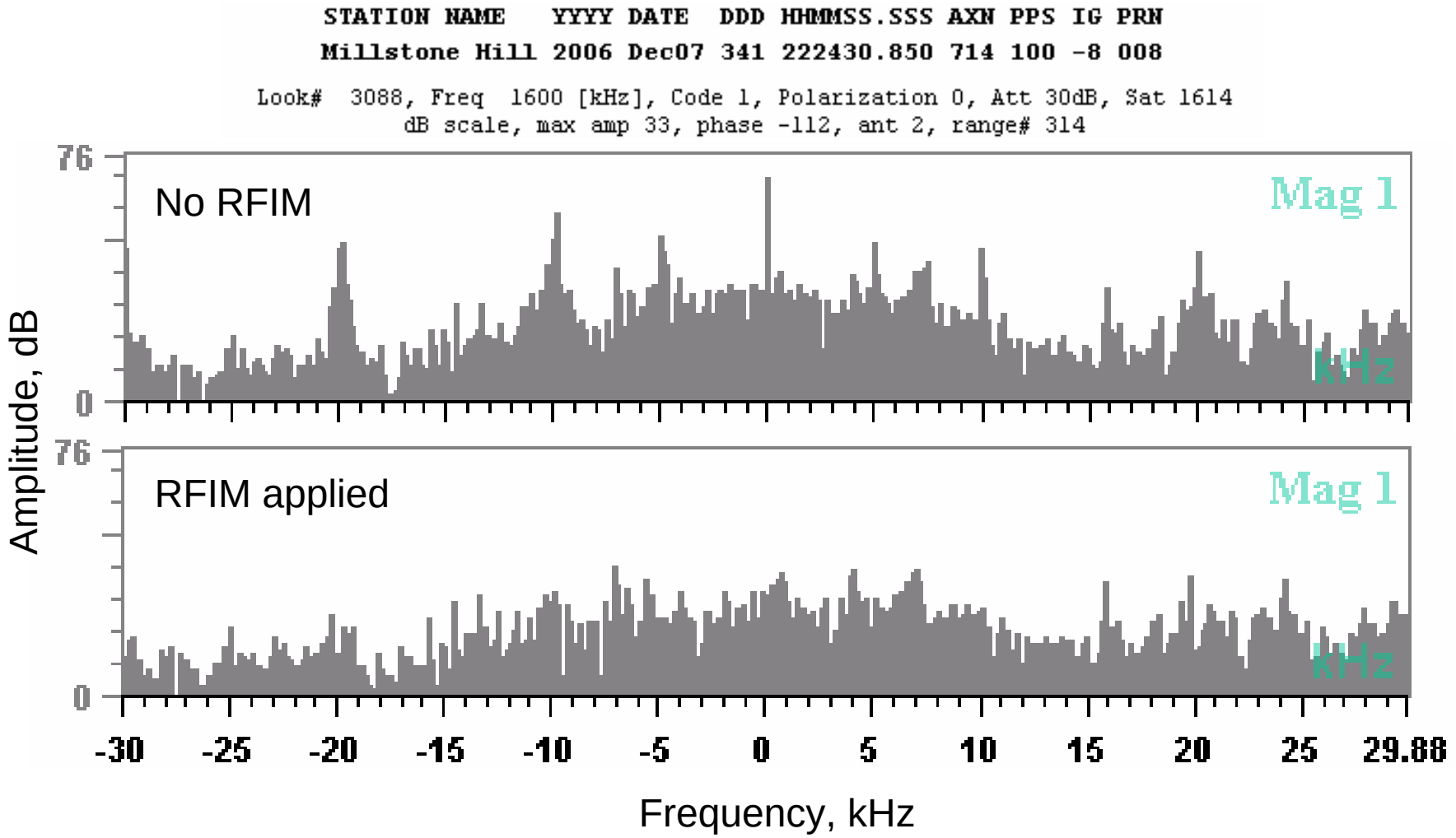
Pre-cleaning algorithm lab test

Loop-back with +5kHz interferer



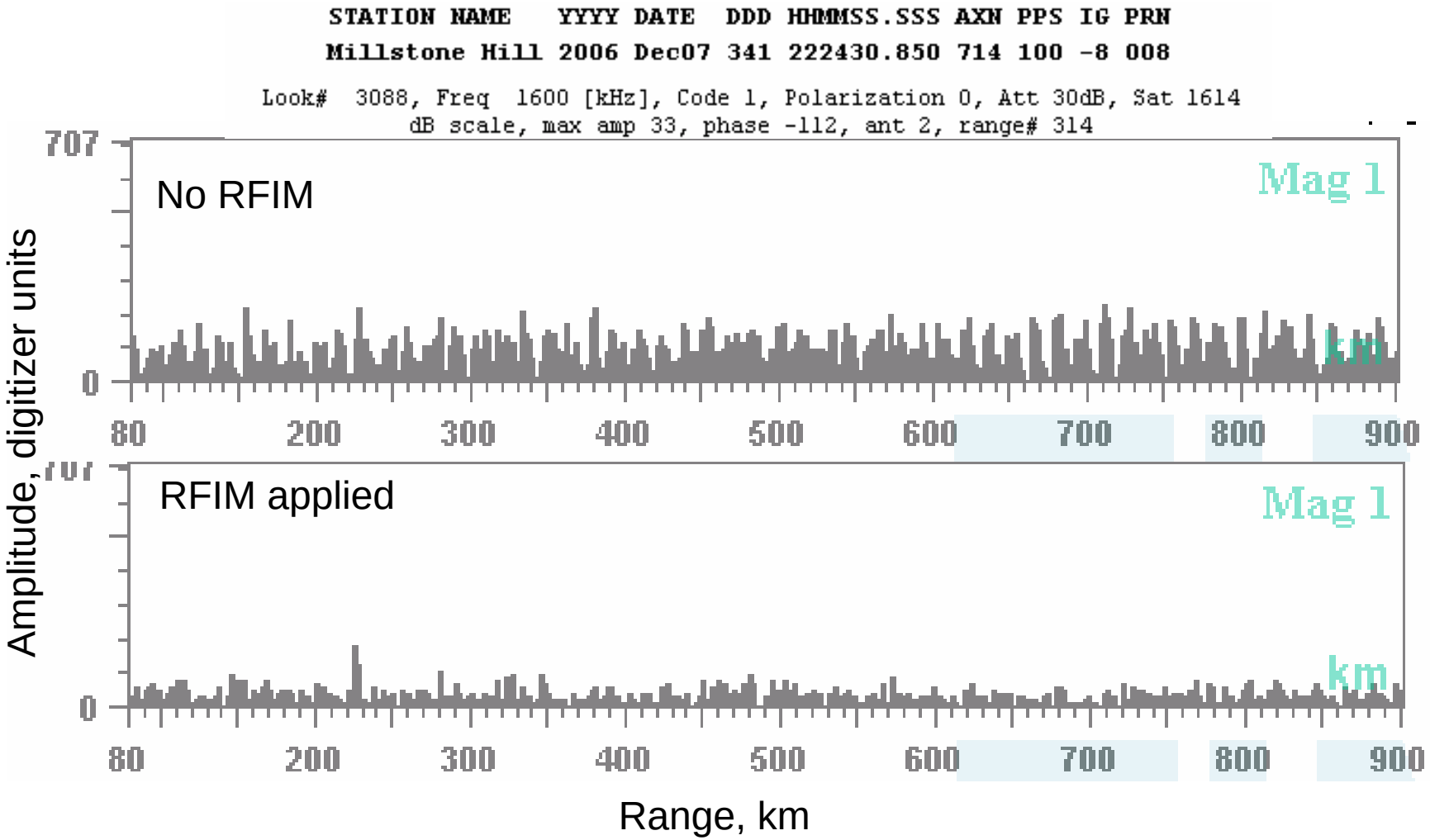
RFIM application example

Frequency domain



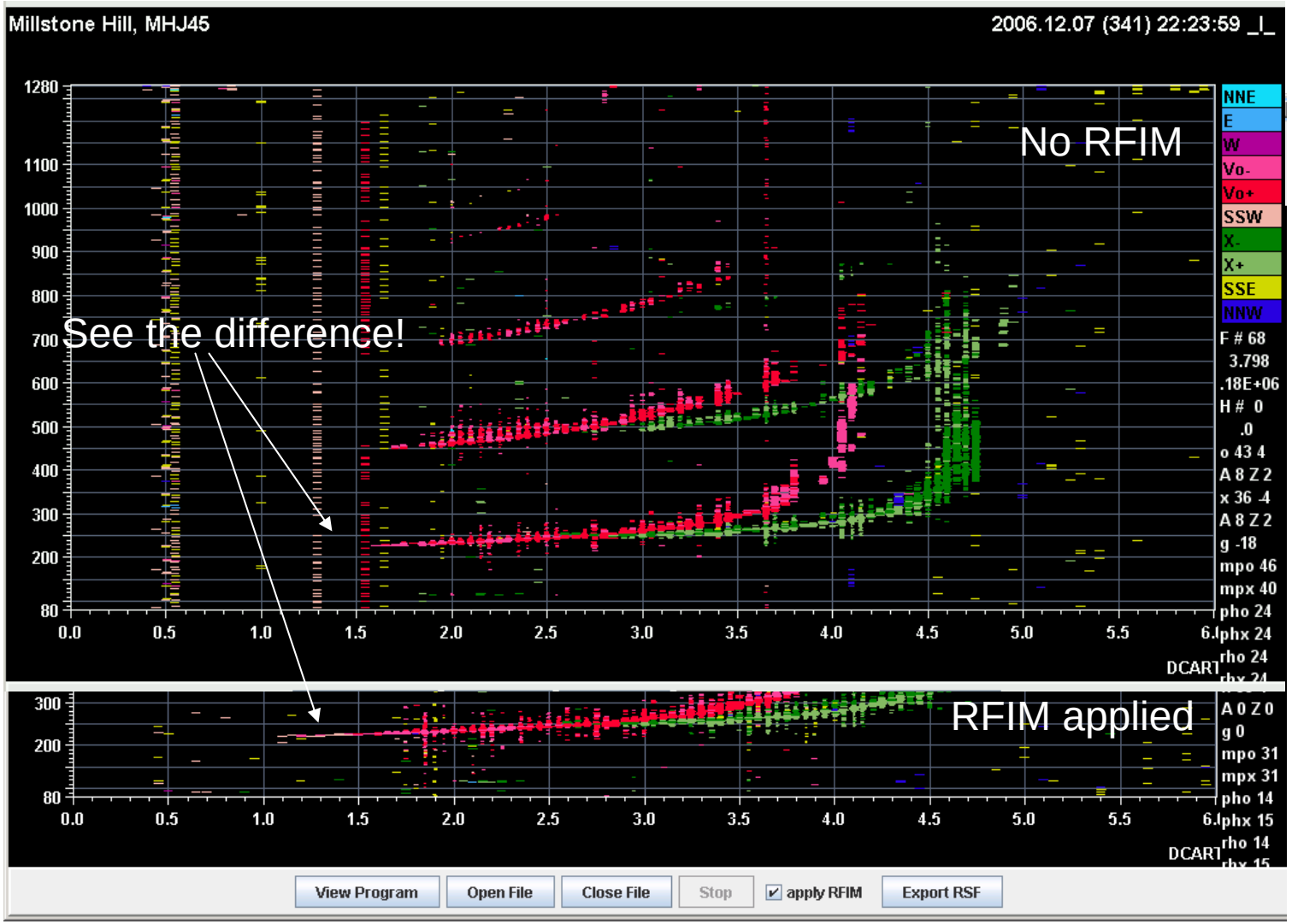
RFIM application example, cont.

Time domain (before FFT)



RFIM application example, cont.

Millstone Hill ionogram



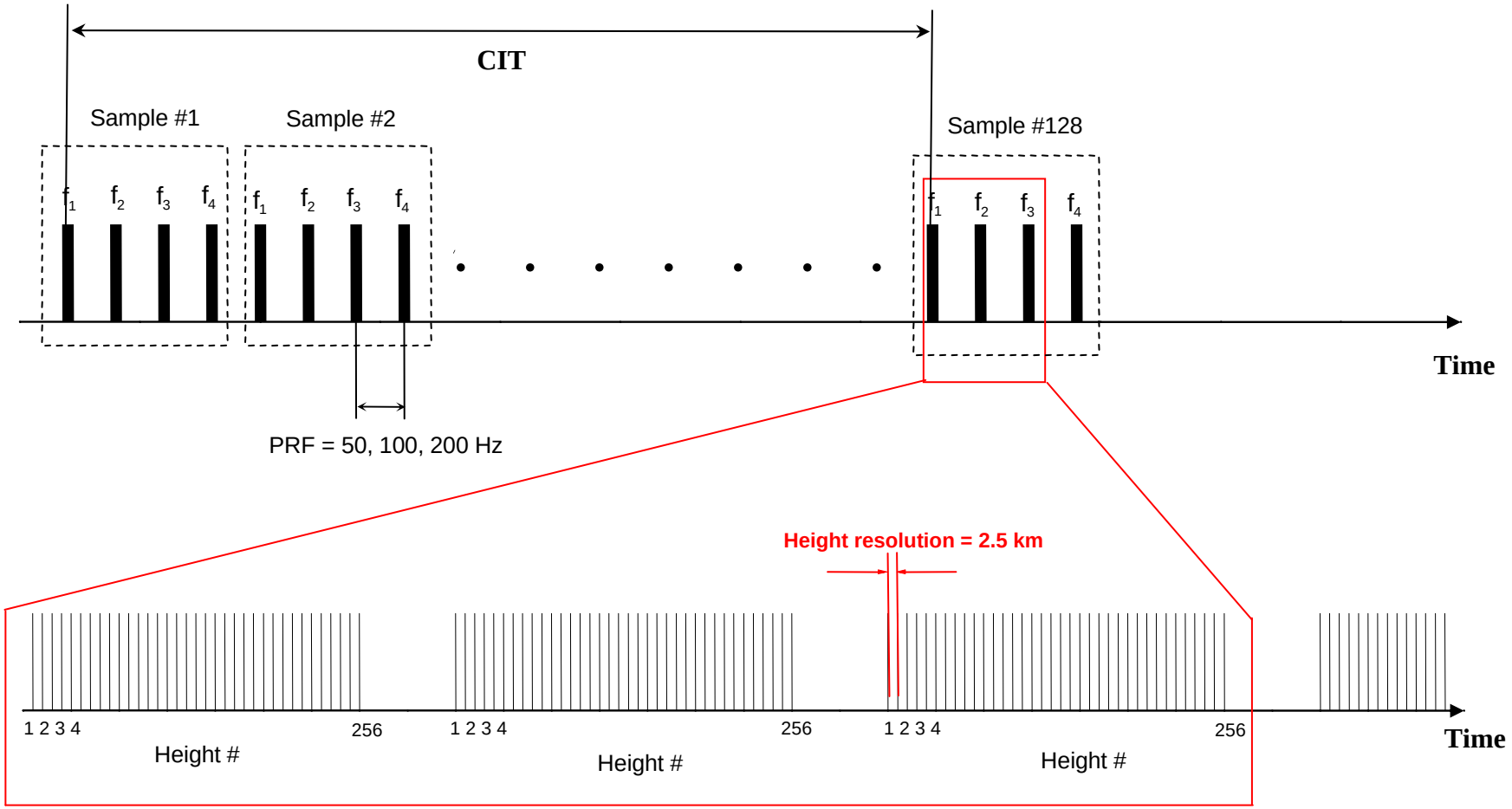
Conclusions

DPS-4D provides an opportunity of implementing sophisticated signal processing algorithms

Application of RFIM technique dramatically improves the ionogram quality in the lower frequency range.

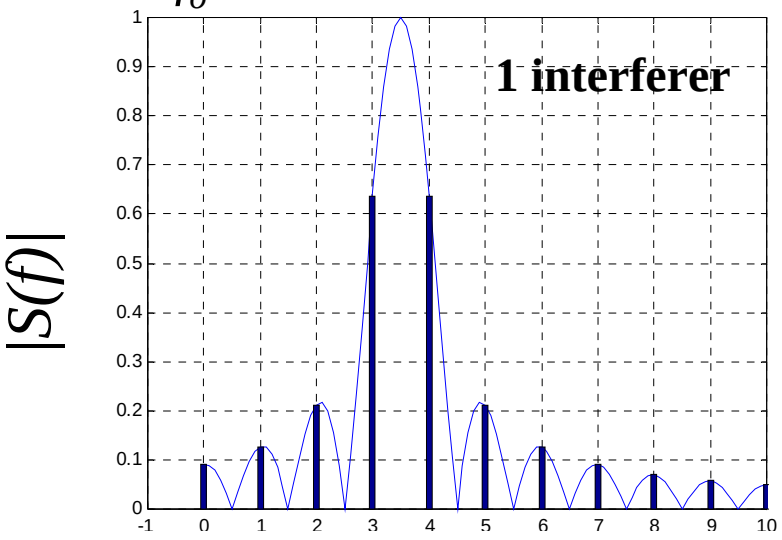
Field-test results are following!

DPS data structure

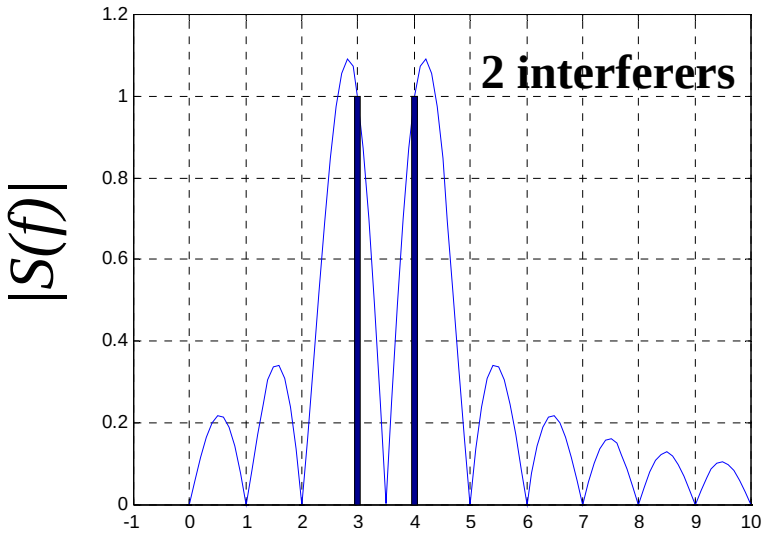


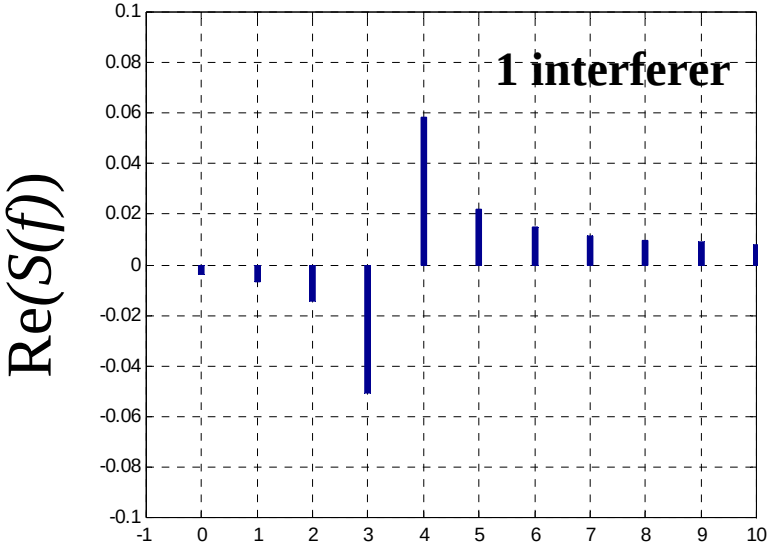
One interferer vs. two close interferers

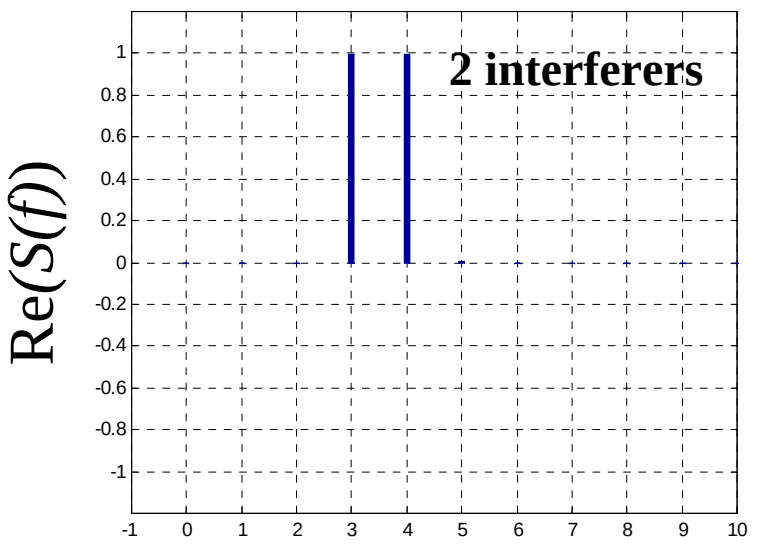
$f_o = 3.5$



$f_{o1} = 3, f_{o2} = 4$

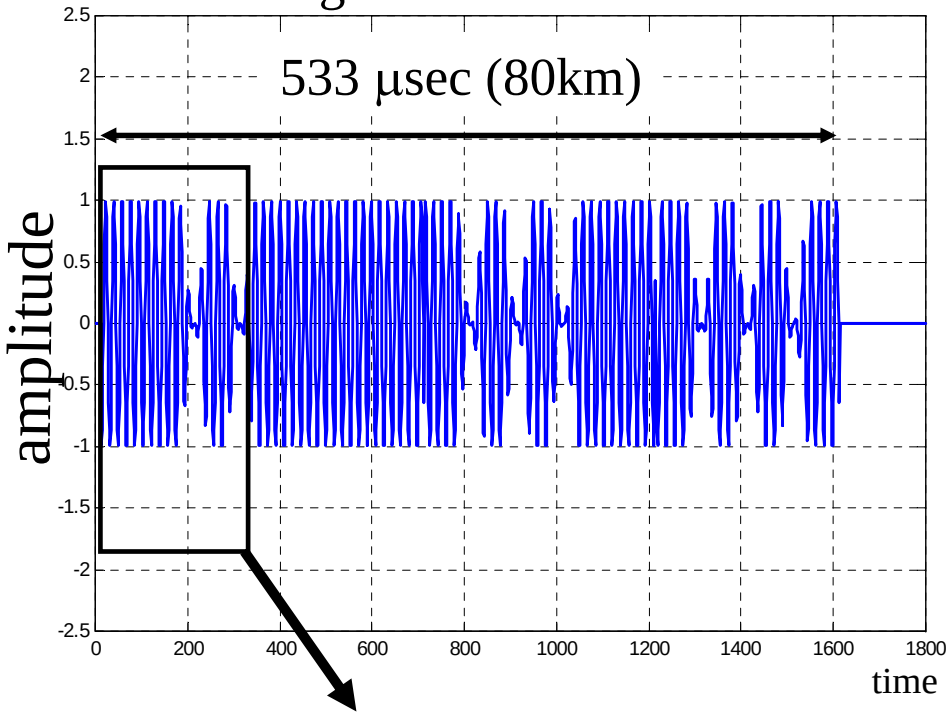


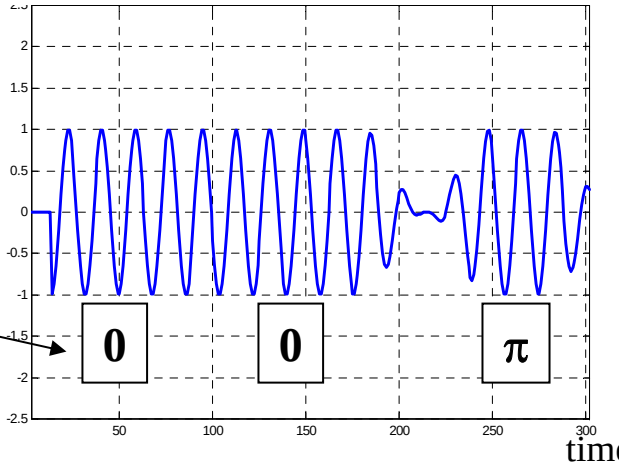




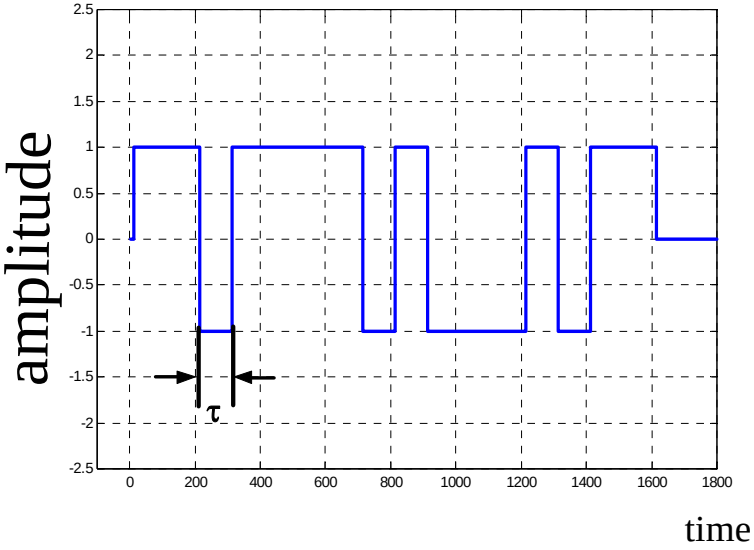
DPS waveforms in time domain

Original waveform





DPS waveform after "phase detection"



τ = 33.33μsec (5km)