Noise
From a Receiver Perspective

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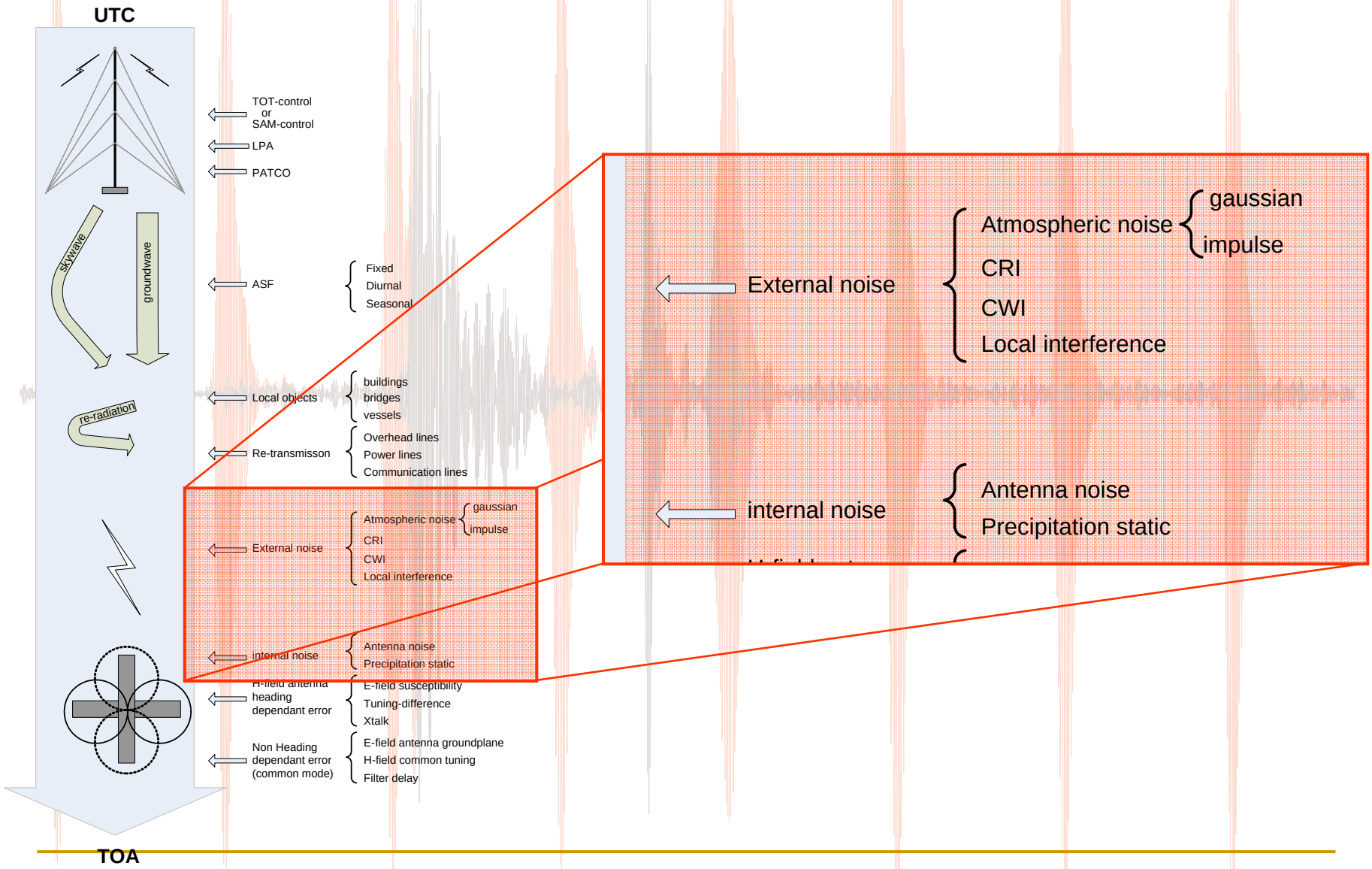
Loran-C error model: Noise & Interference



Noise and interference

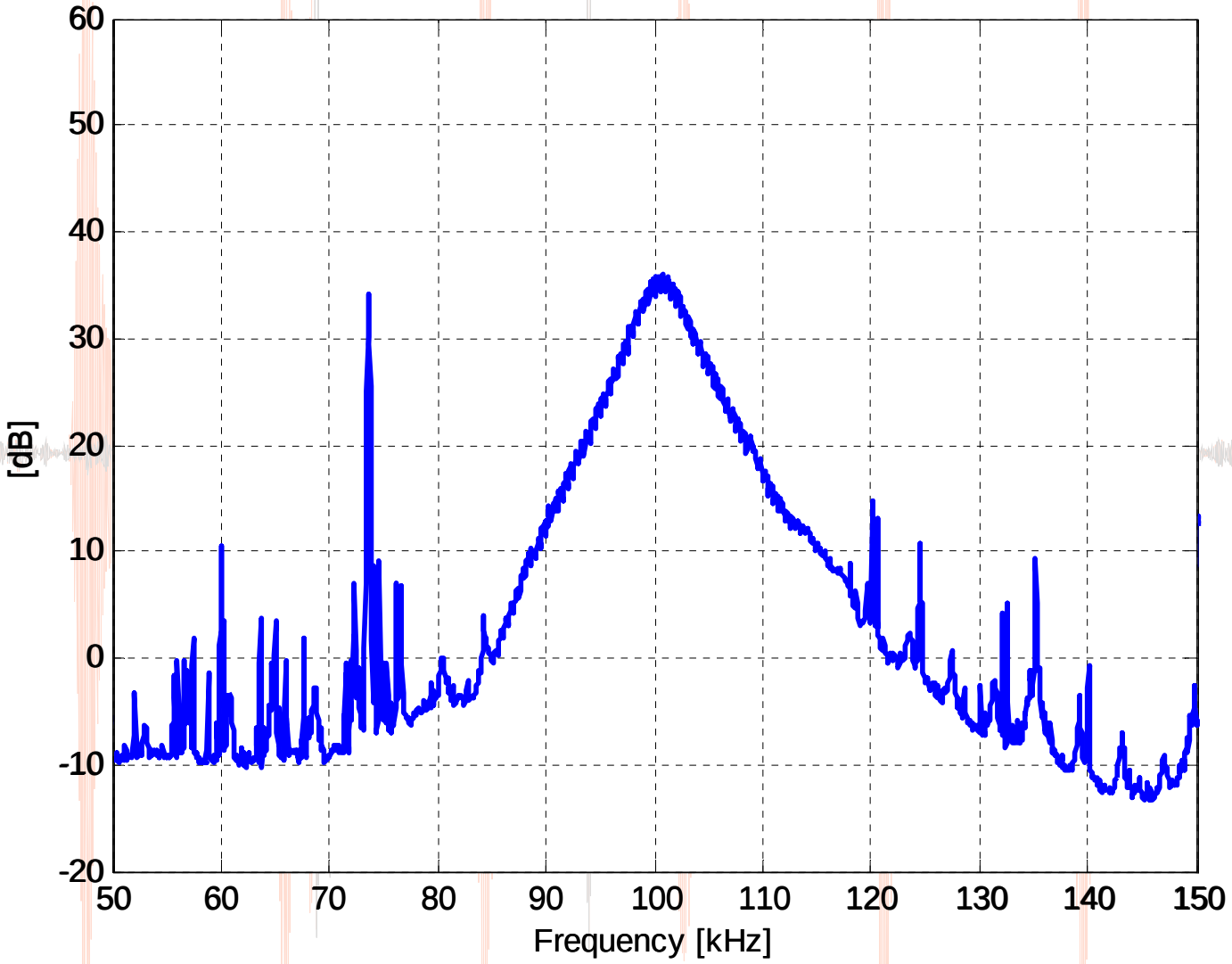
- Noise & Interference
  - Atmospheric noise
  - Cross-rate
  - CWI
  - Local interference
- Noise measurements and analysis → research
- Noise mitigation → receiver technology

Multi-domain Noise Mitigation

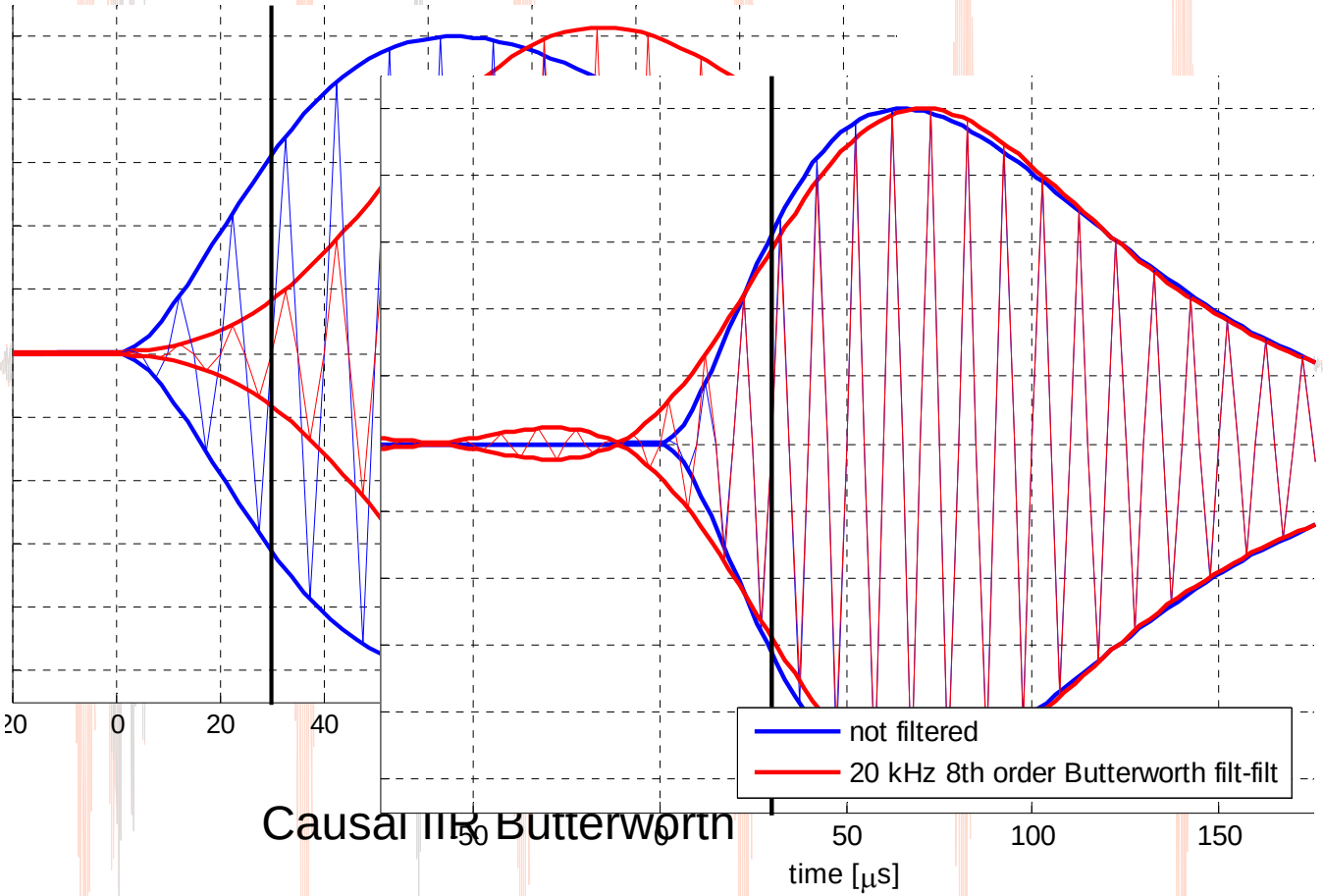
Noise mitigation possible if the undesired signals differ from the desired signal in one or more domains:

- Frequency domain
- Coding domain
- Time domain
- Spatial domain
- Polarization
- E-field vs. H-field

CWI: Frequency Domain



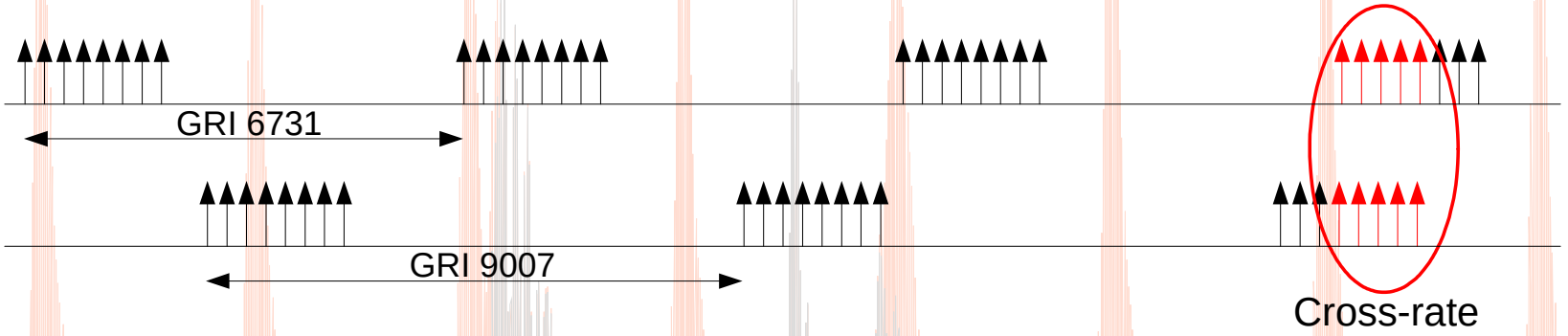
CWI mitigation: bandpass filtering



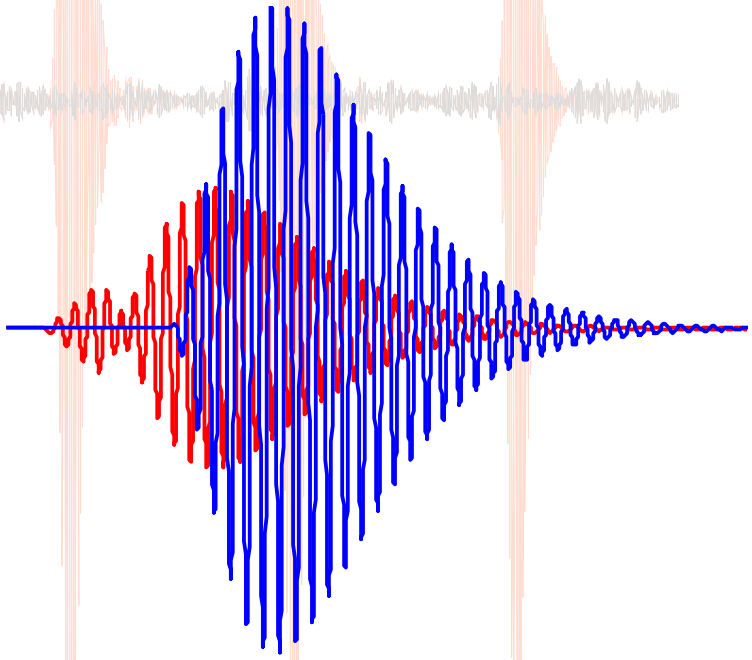
Causal IIR Butterworth

Non-Causal IIR Butterworth (matlab filtfilt)

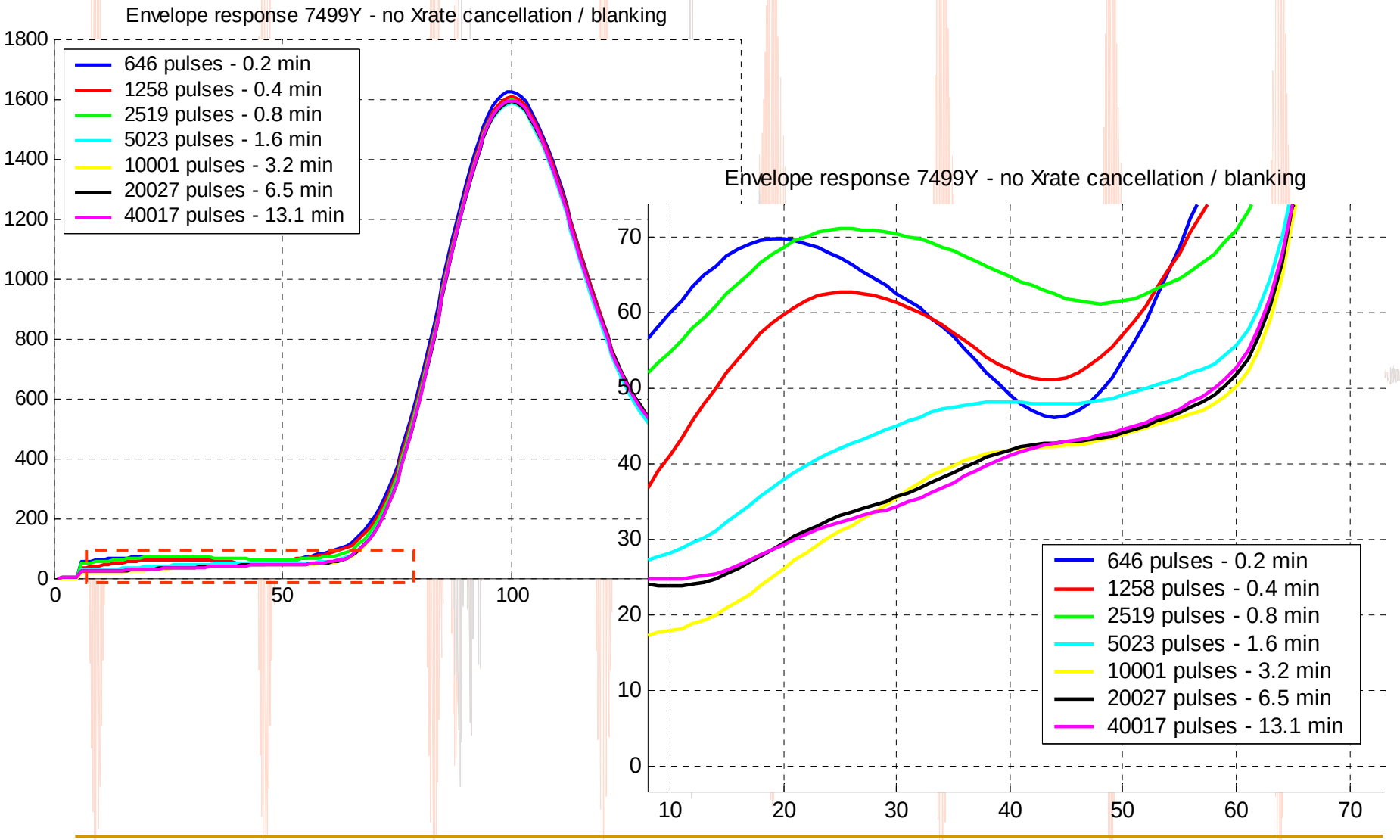
Cross-Rate: Coding Domain



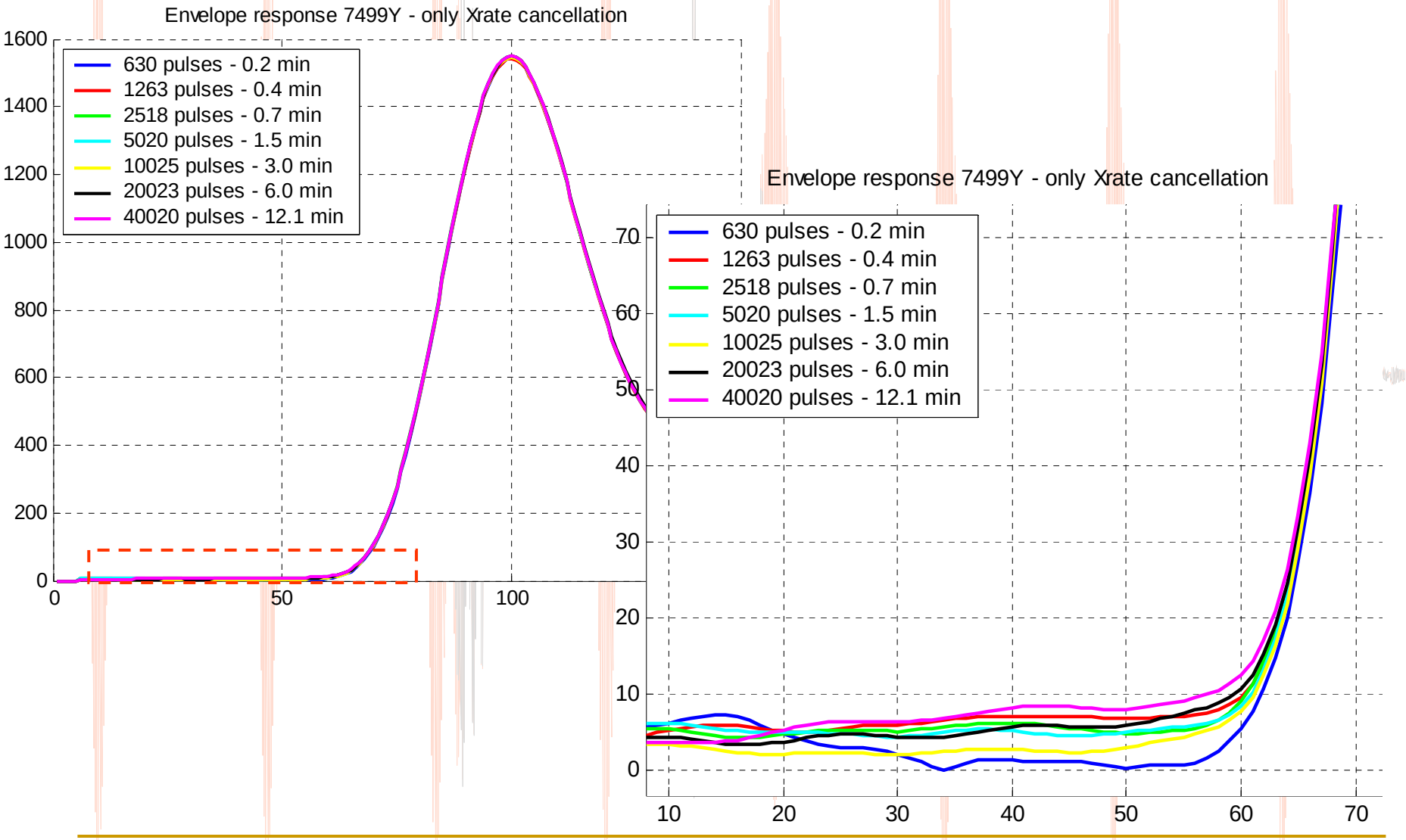
- Distant stations are unusable for positioning but their skywaves can still cause a lot of Xrate
- Phase code design not ideal



Xrate mitigation by averaging



Xrate mitigation by canceling + averaging



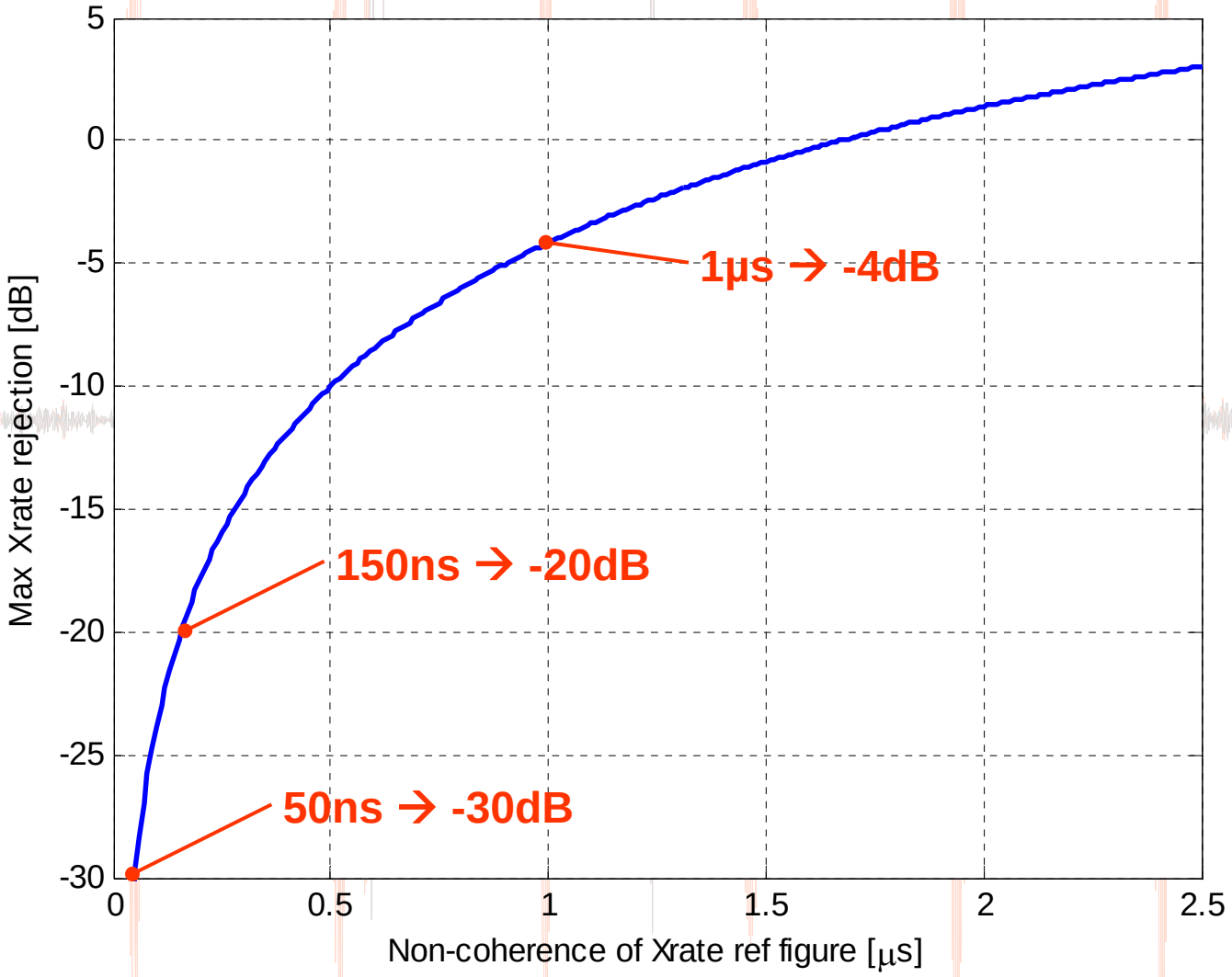
The challenges of Xrate cancellation

- Noise
- Unknown dynamics
  - Movement
  - rotation
- Unknown blanking
  - Unknown guard intervals
  - Unknown state of alternate blanking

  } eLoran signal spec
- Unknown data modulation
- Transmitter stability
  - Phase jitter: 50ns?
  - Amplitude jitter: 2%?

  } Transmitter upgrades?

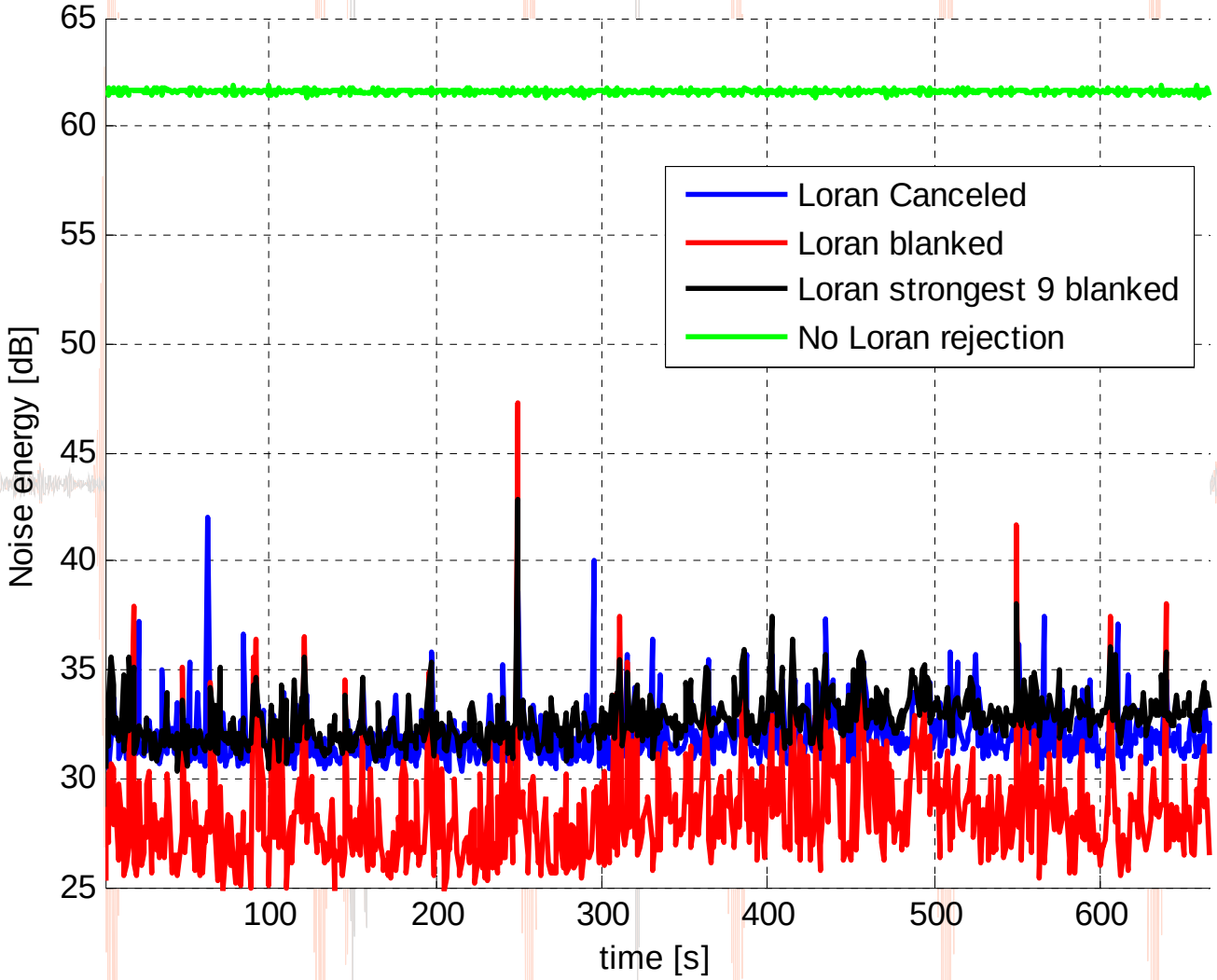
The effect of (uncompensated) dynamics on Xrate cancellation



Xrate cancellation: conclusions

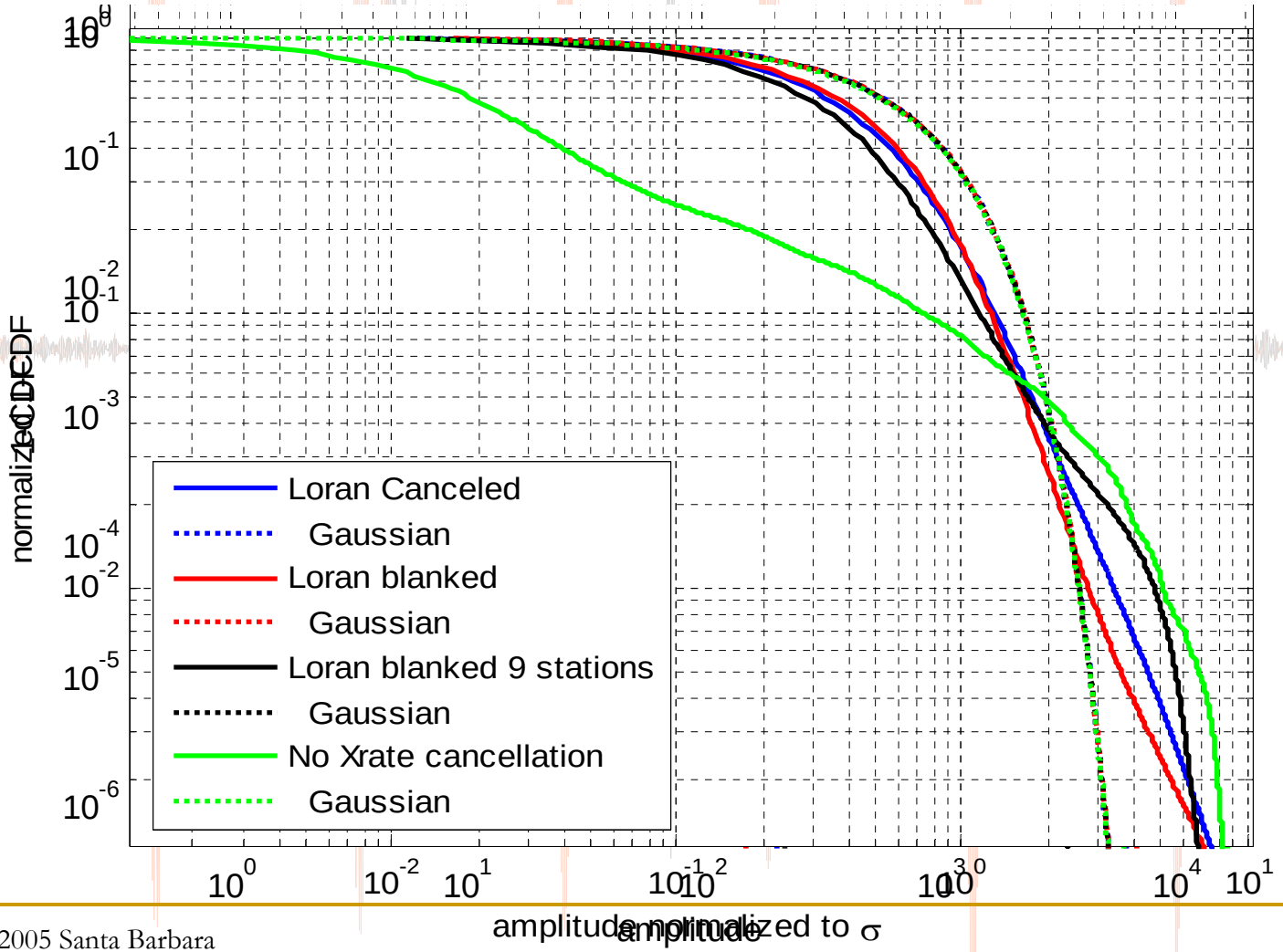
- Theoretically the best option: removal of the ‘noise’ while maintaining all the signal
- Receiver manufacturers need detailed, stringent and accurate signal spec
- The current transmitter stability already limits the maximum Xrate cancellation to about 30dB.
- Noise and dynamics might further decrease canceling effectiveness

Noise levels: Atmospheric noise



Note: Loran signal loss due to blanking not taken into account

Cumulative Distribution Function of a ‘clean’ dataset



Calculating the Hole Punching Gain

- From the PDF we can calculate the amount of energy above and below this threshold:

$$E_{AboveThreshold} = 10 \cdot \log\left(\sum_{A=threshold}^{\infty} PDF(A) \cdot A^2 \right)$$

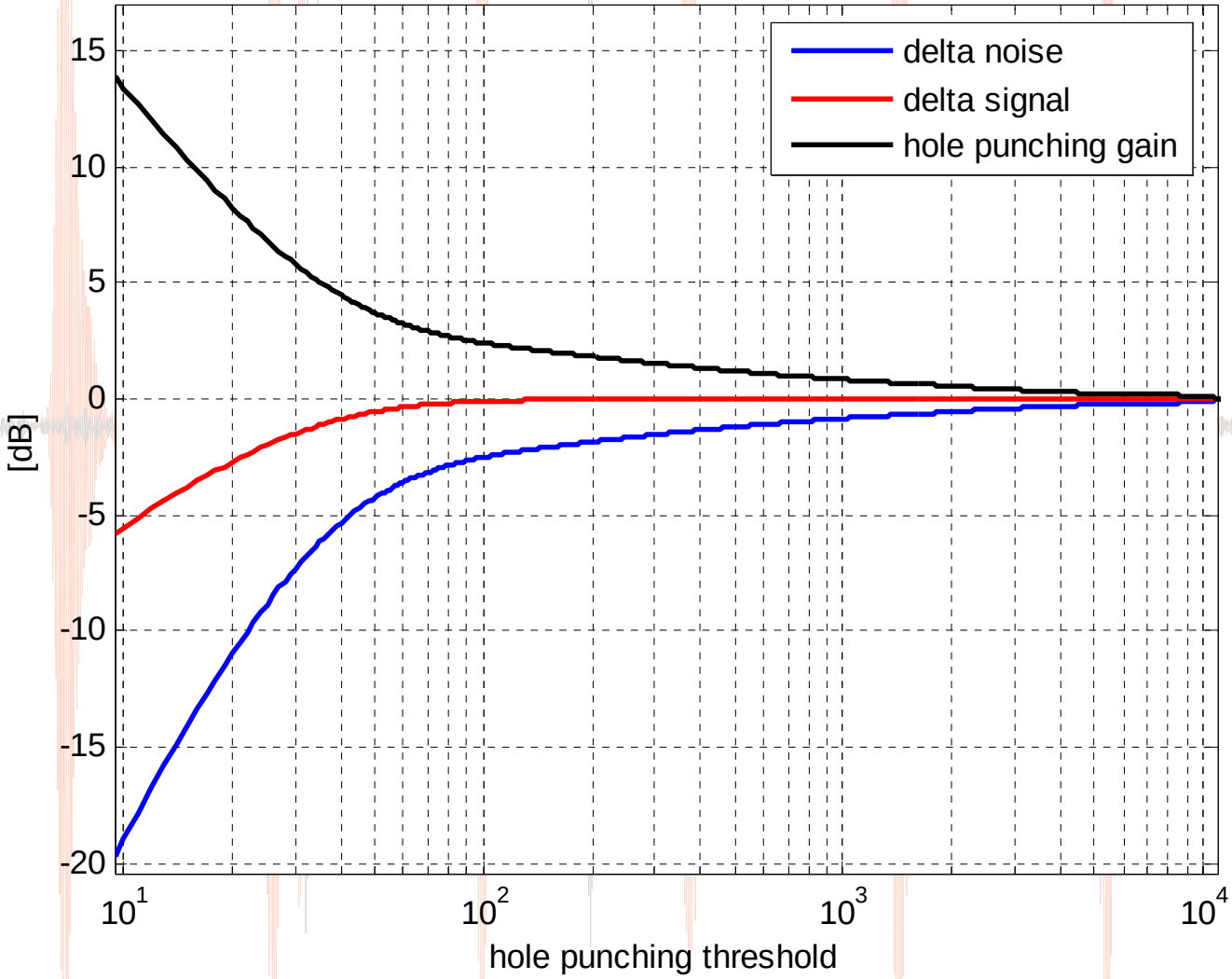
- So the total noise reduction becomes:

$$\Delta Noise = 10 \cdot \log\left(\frac{\sum_{A=threshold}^{\infty} PDF(A) \cdot A^2}{\sum_{A=0}^{\infty} PDF(A) \cdot A^2} \right)$$

- The impact on the signal:

$$SignalReduction = 10 \cdot \log\left(1 - CDF(threshold)\right)$$

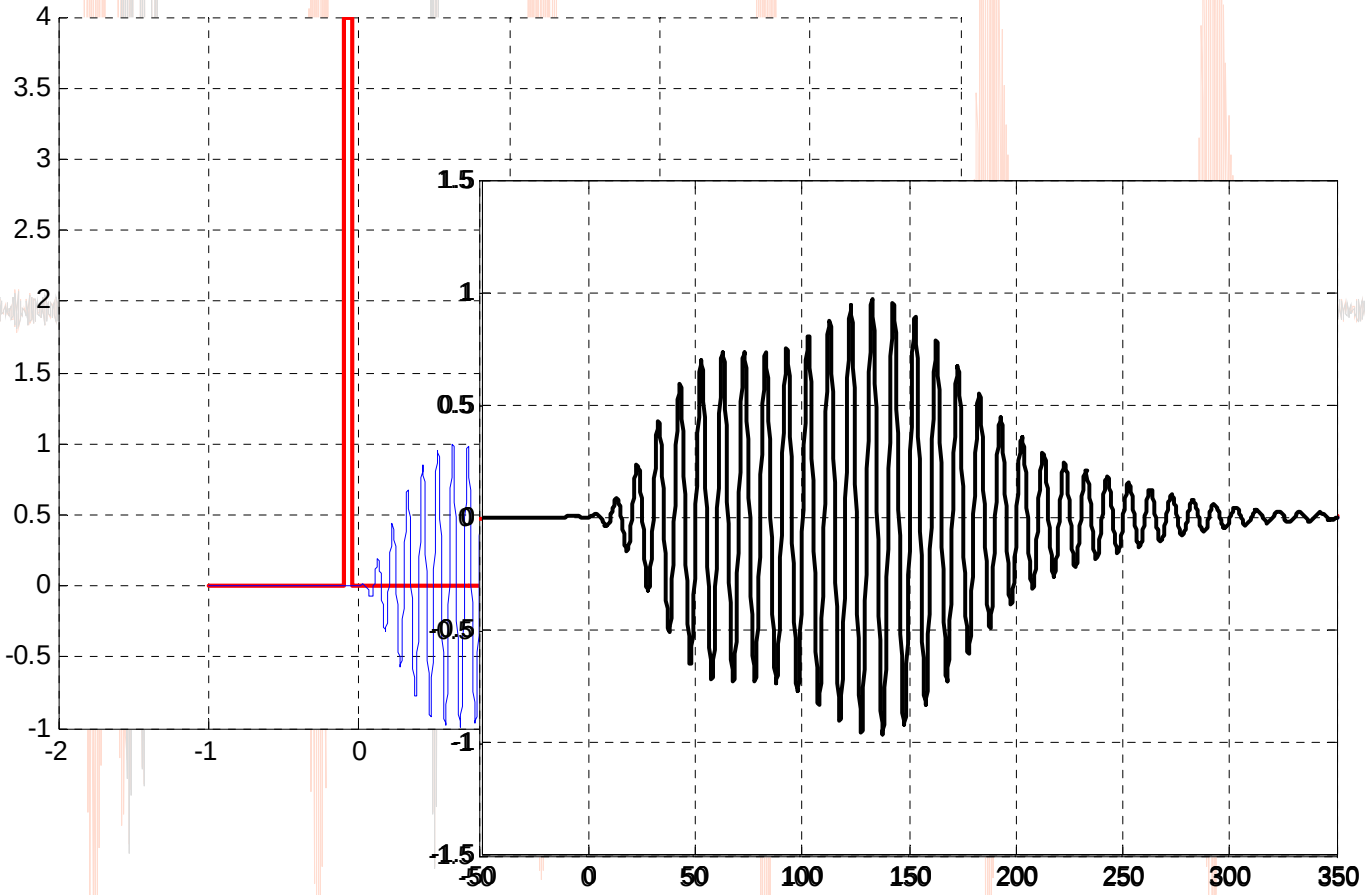
Calculated Hole Punching Gain for a clean dataset



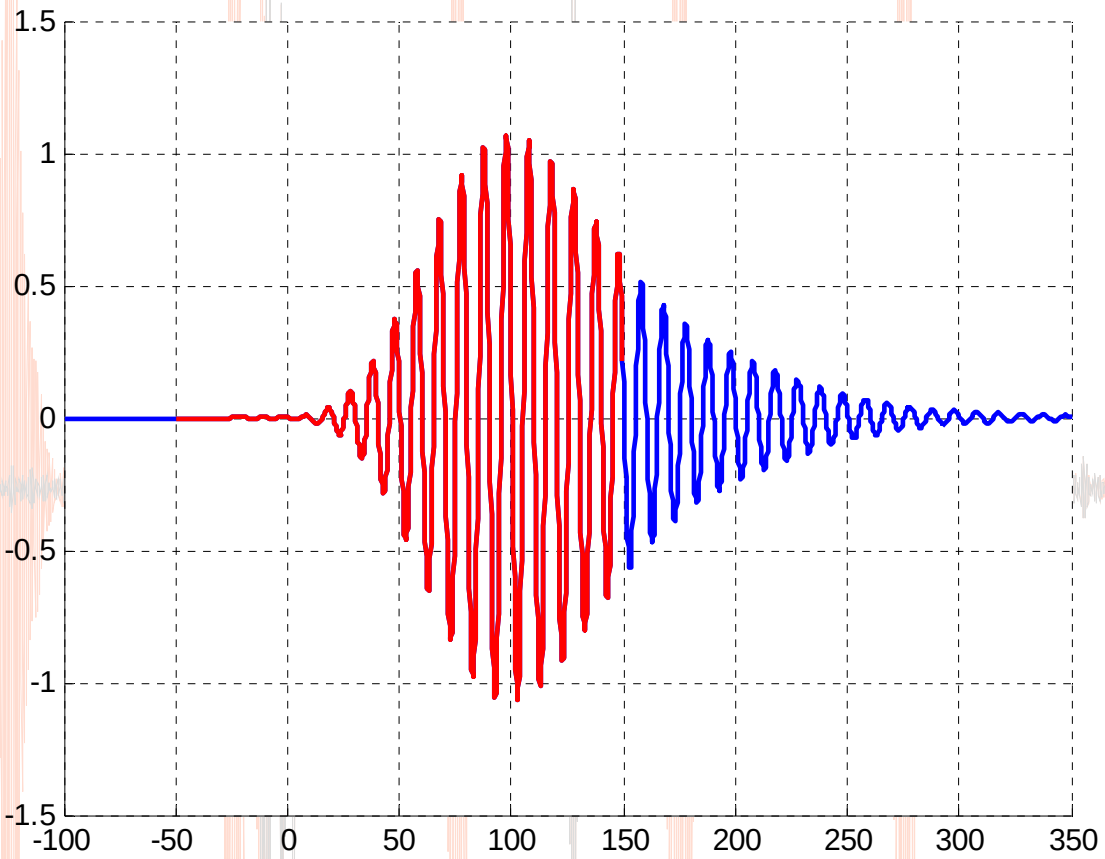
Hole Punching Implementation

- Replace contaminated samples by zero or clip them
  - Pre-bandpass
  - Post-bandpass
- Detect contaminated *samples* and disregard them for tracking
  - This implies partially updating the Loran average
- Detect contaminated *Loran pulses* and disregard the complete pulse for tracking (from now referred to as ‘Loran Punching’)

Duration of a *filtered* Noise Spike
It can't be much shorter than a Loran pulse

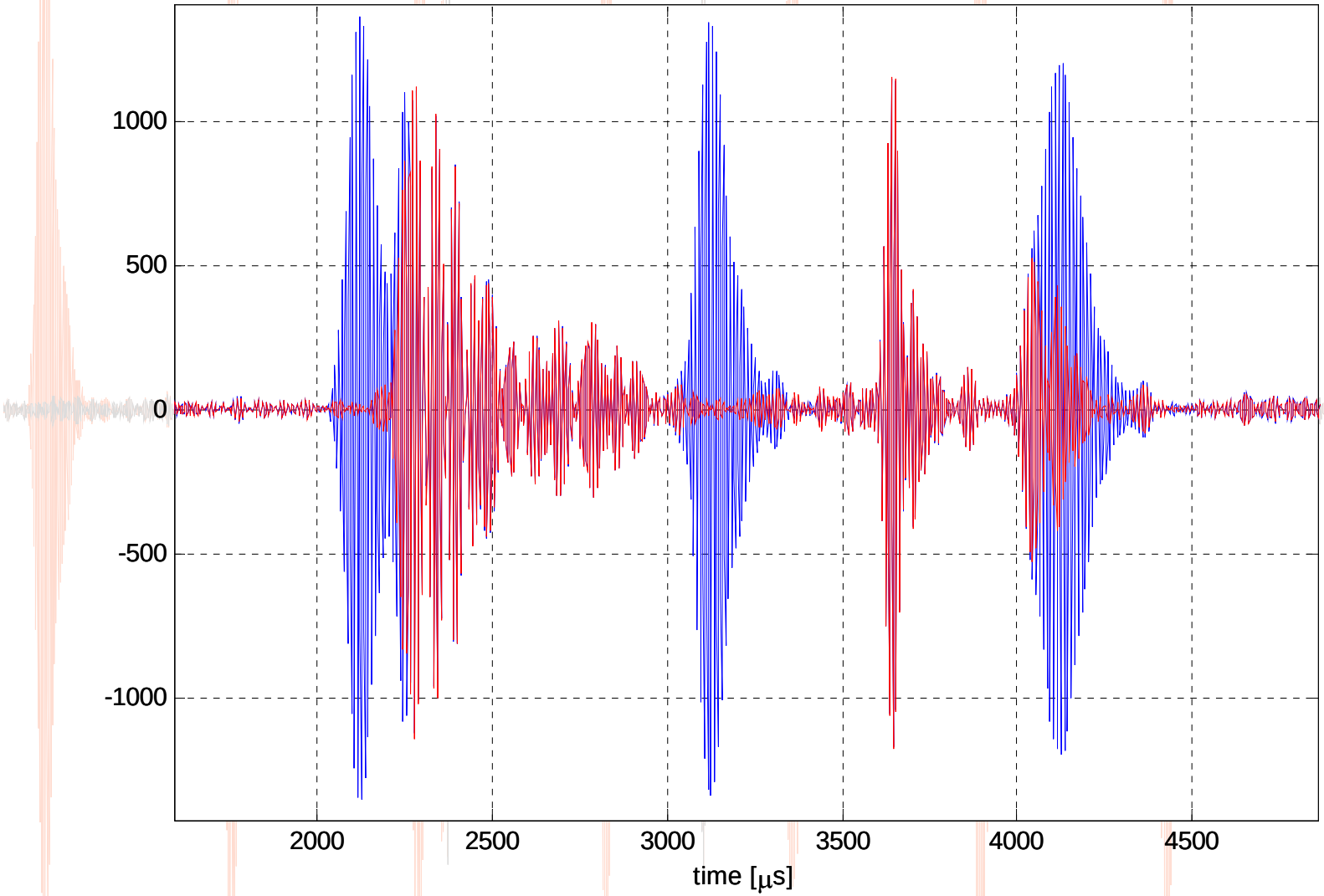


Loran Pulse Punching

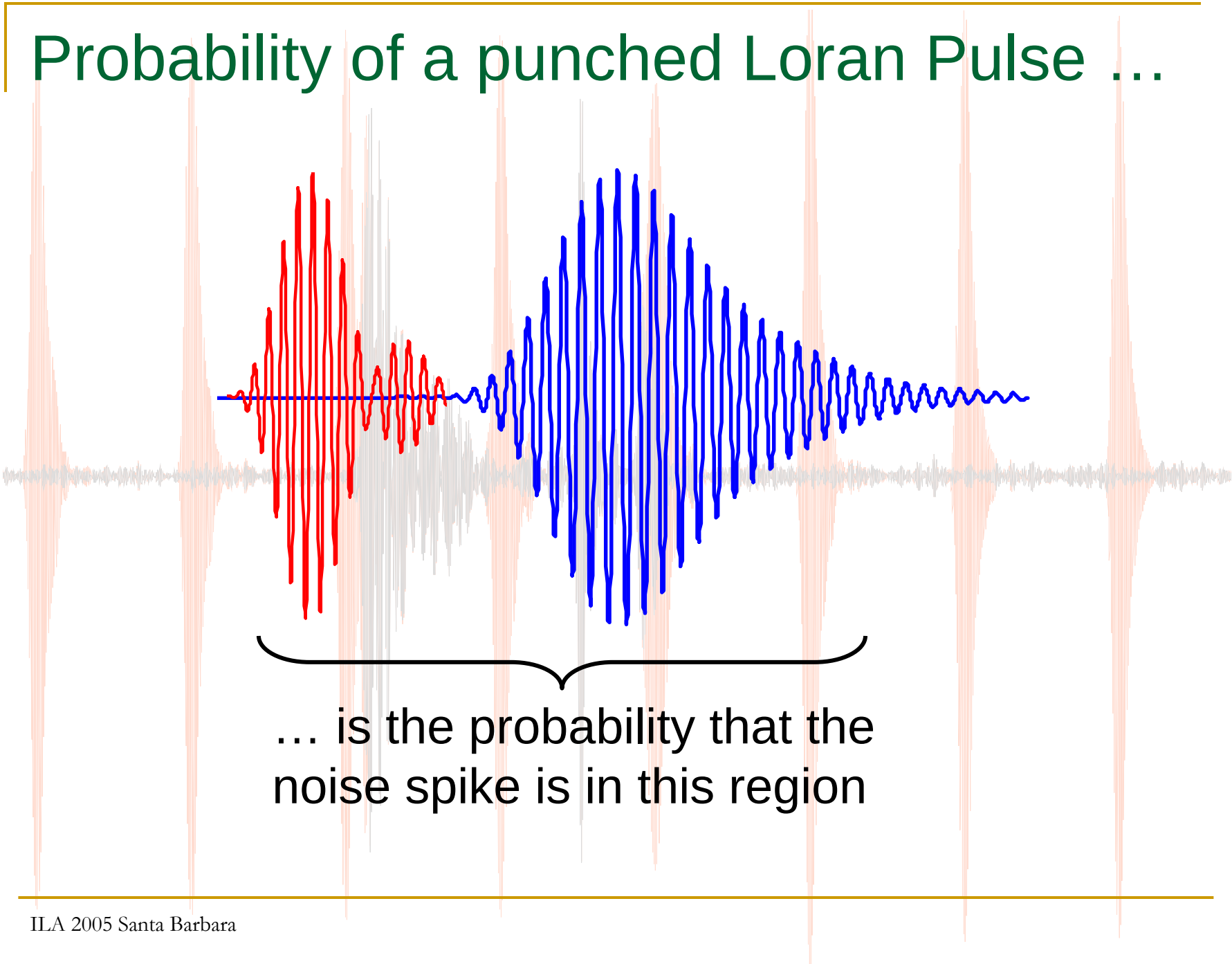


If a (certain area of a) Loran pulse is hit by a noise spike, we blank the complete Loran pulse

Loran Pulse Punching

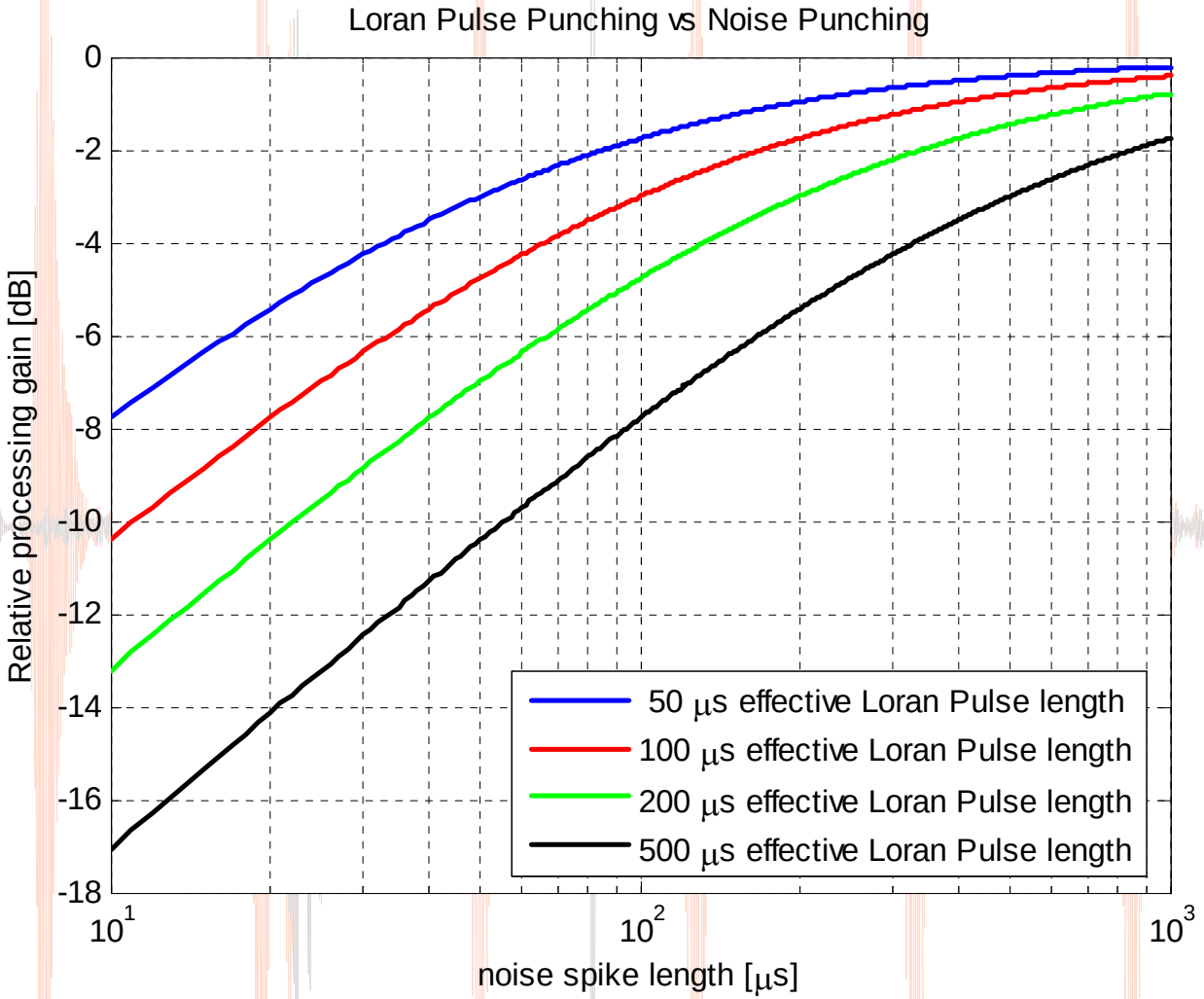


Probability of a punched Loran Pulse …



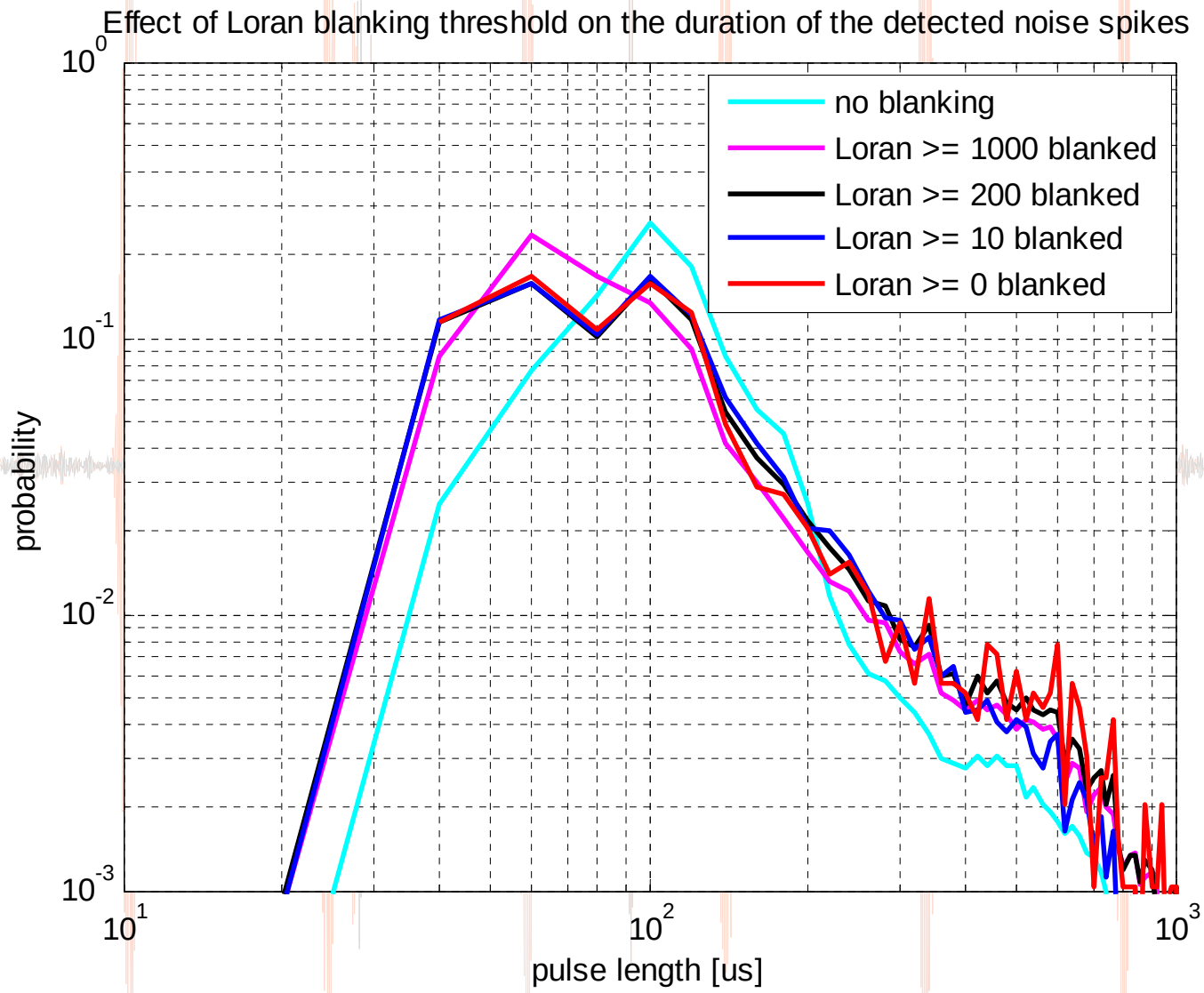
… is the probability that the noise spike is in this region

“Loran Punching” vs. “Noise Punching”

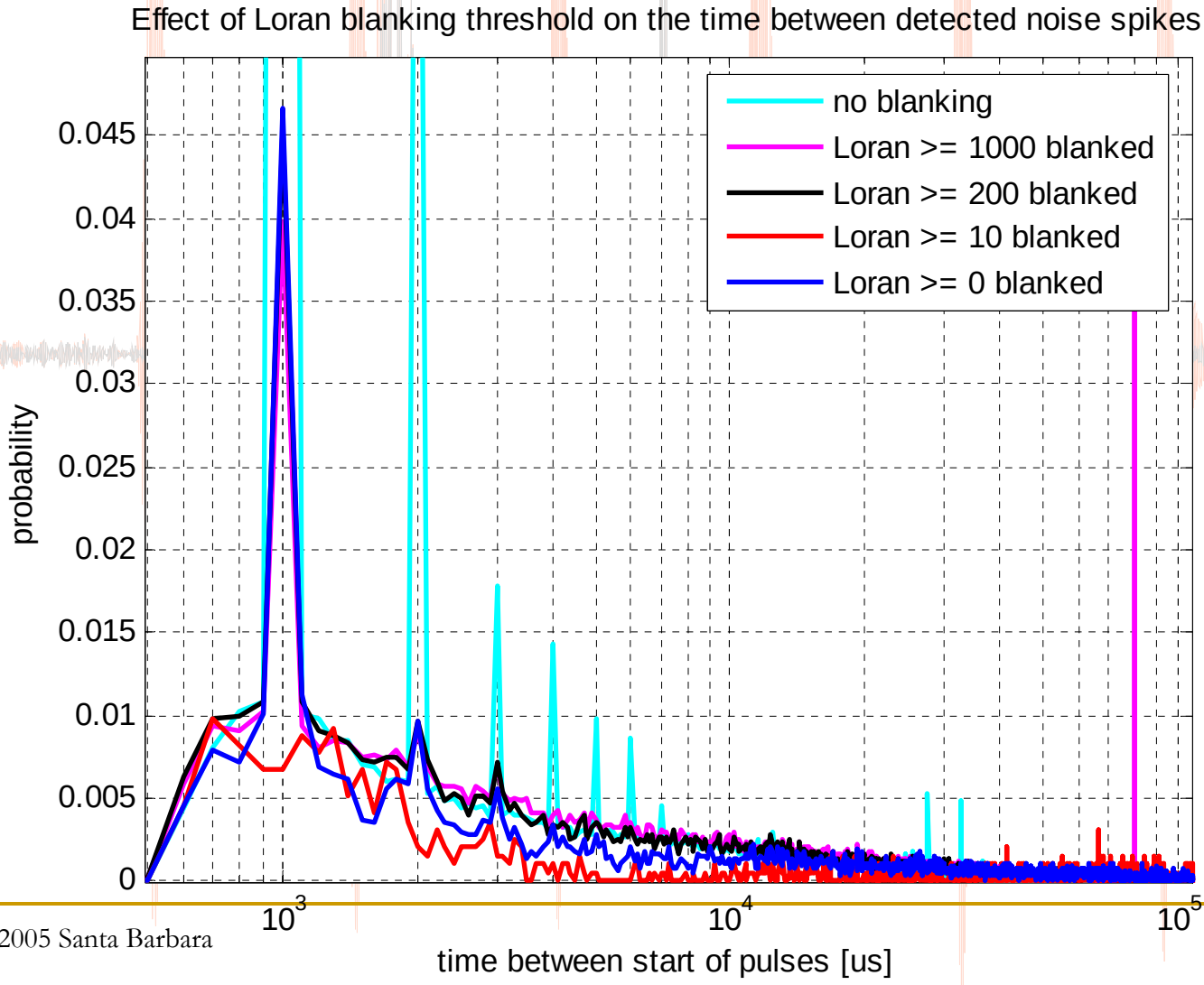


Noise energy is assumed constant: if the average noise spike is twice as long, we have only half as many of them

Measuring the duration of a noise spike



Time between noise spikes



Recommendations for further research

- Collect atmospheric data for various weather types:
  - quiet
  - tropical
  - frontal
- Determine PDF statistics
- Determine noise spike statistics
- Determine hole punching gain using ‘Loran Pulse Punching’ (Rx approach)
- Determine hole punching gain using ‘Noise Punching’ (Theoretical approach)
- Compare both methods
- Performance analysis of actual receiver implementation