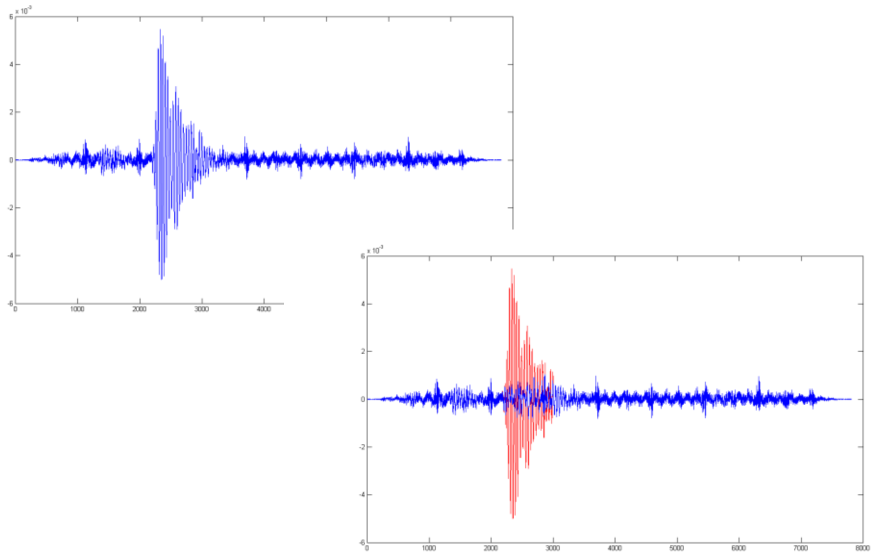
Impulse-Noise Cancelation using the Common Mode Signal



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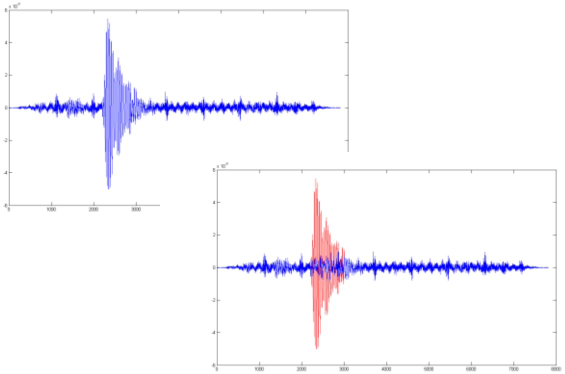
Overview



- Why the need to cancel impulse noise?
- Differential and common-mode signals
- NEXT and FEXT
- Impulse noise detection
- Normalized LMS canceler
- Stability and convergence
- Simulation results
- Suggestions for improvement

Impulse noise

- bursts of high amplitude, high peak to rms
- most of the energy contained below 200kHz
- large amplitudes that occur too frequently – outliers – does not fit the Gaussian model

- **Causes**
  - electromagnetic coupling, inductive coupling
  - switching of home appliances, lightning strikes, automobile ignition, trains, electrical engines, etc.

- affects communications – corrupts the transmission signal – Internet, IPTV, etc.

Fig. 1 - Image corrupted by impulse noise

Differential and common-mode signals

DM signals:

- sent on 2 wires, opposite polarity with respect to GND.
- almost equal amplitudes
- RX measures signal difference between wires
- for twisted cables, interference in DM couples almost in the same way
- improved SNR

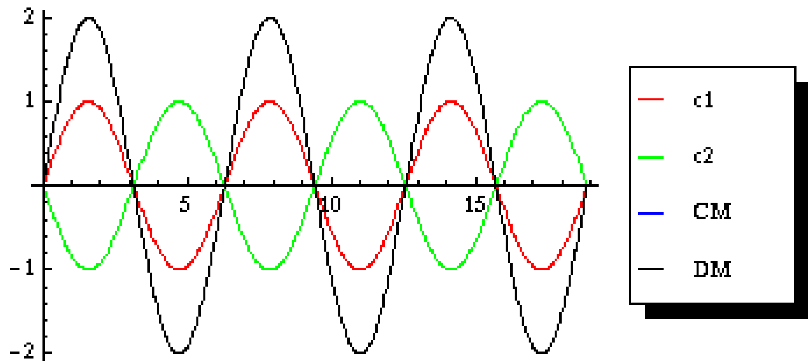
$$x_{DM}=c_2(t)-c_1(t)$$

CM signals:

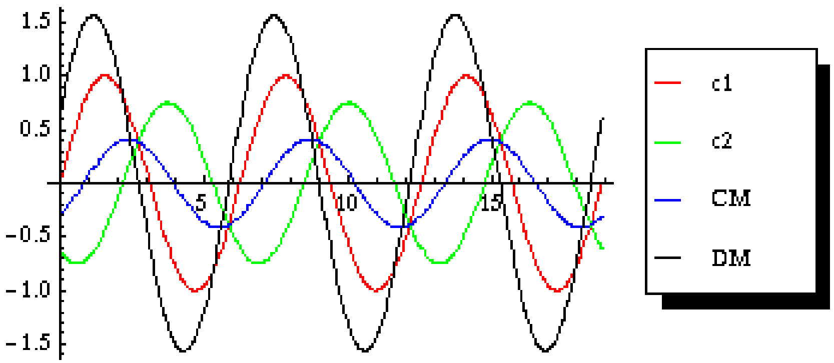
- appear on both lines on a 2-wire cable
- in phase and with equal amplitudes
- arithmetic mean
- noise couples higher
- measured at center tap of transformer

$$x_{CM}=[c_2(t)+c_1(t)]/2$$

- perfectly balanced, no external interference, no CM signal

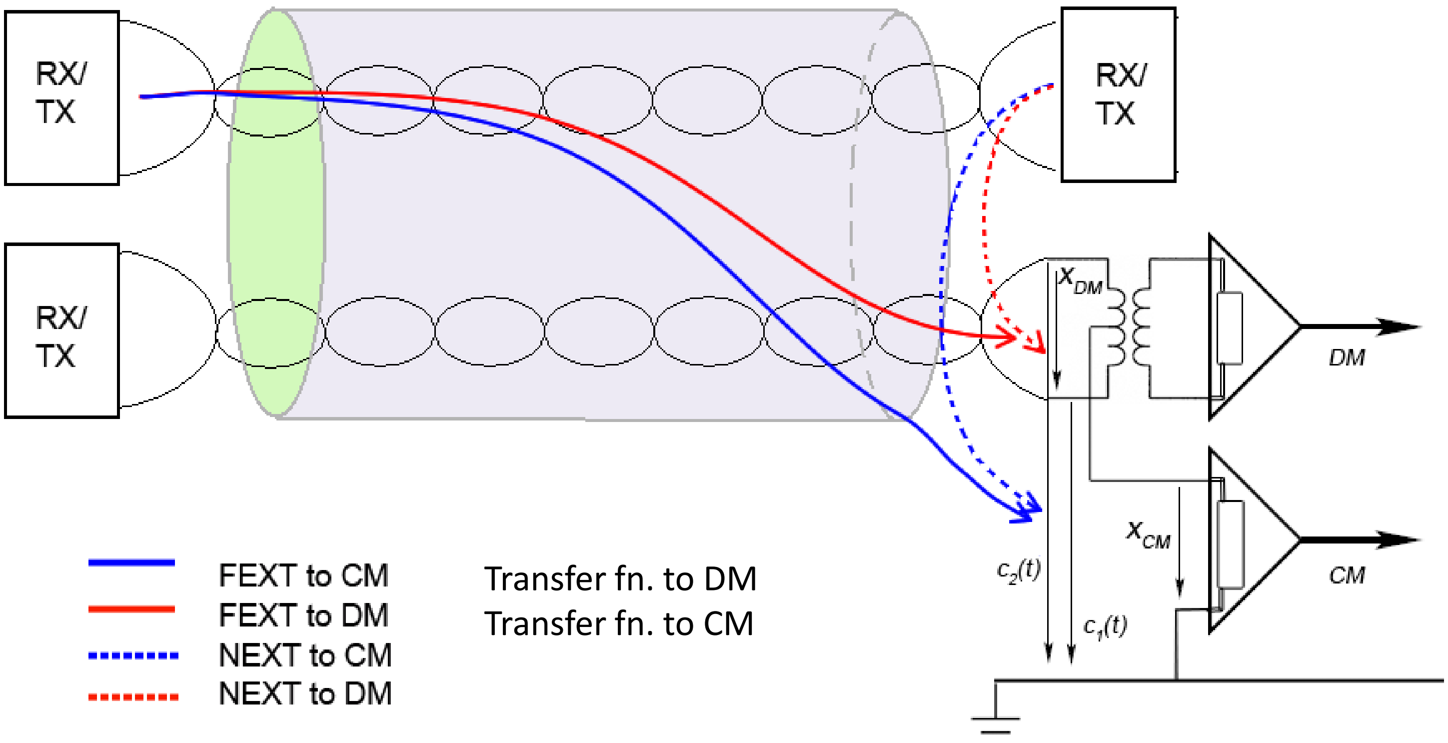


- not perfectly balanced, high coupling into CM



- why twist pairs?
- why interference couples higher into CM?
- in practice, twisted pairs are not perfectly balanced

NEXT, FEXT and transfer functions



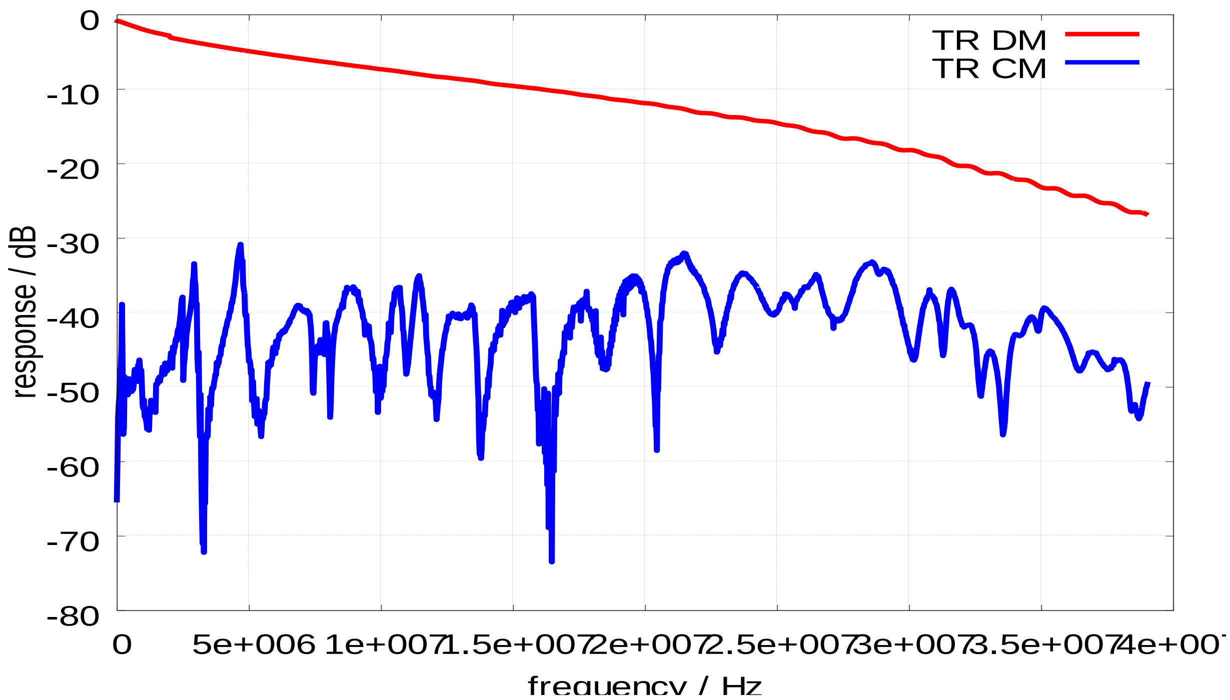
Far End Crosstalk (FEXT) is interference between two pairs in one cable as measured at the end of the cable furthest from the transmitter.

Near end crosstalk (NEXT) is interference between two pairs in one cable as measured at the end of the cable nearest to the transmitter.

NEXT, FEXT and transfer functions

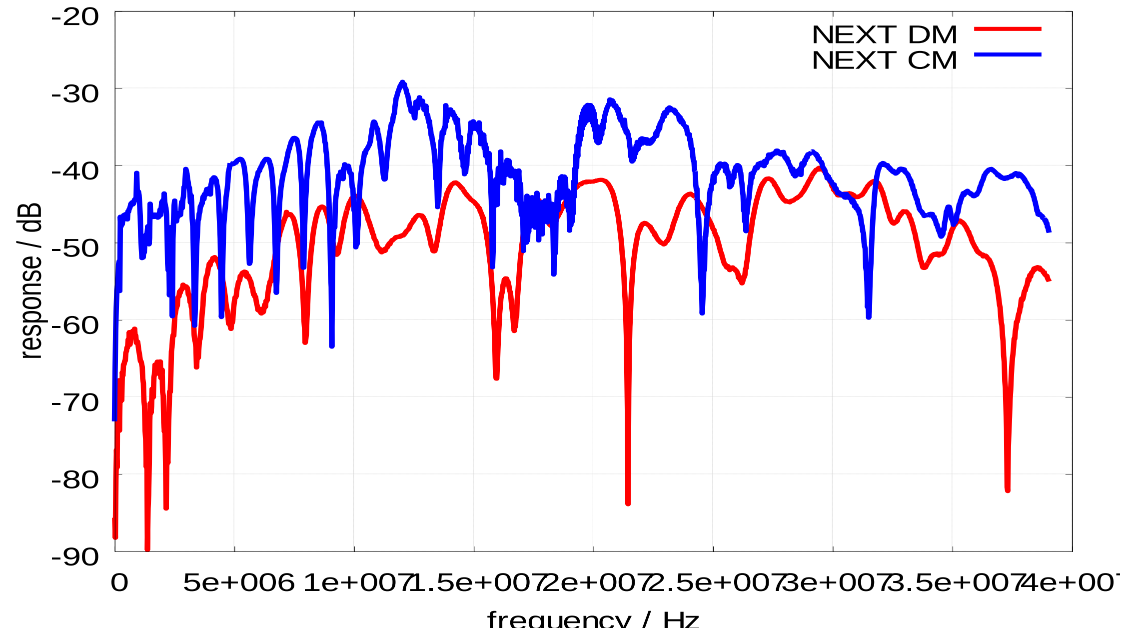
DM transfer function
CM transfer function

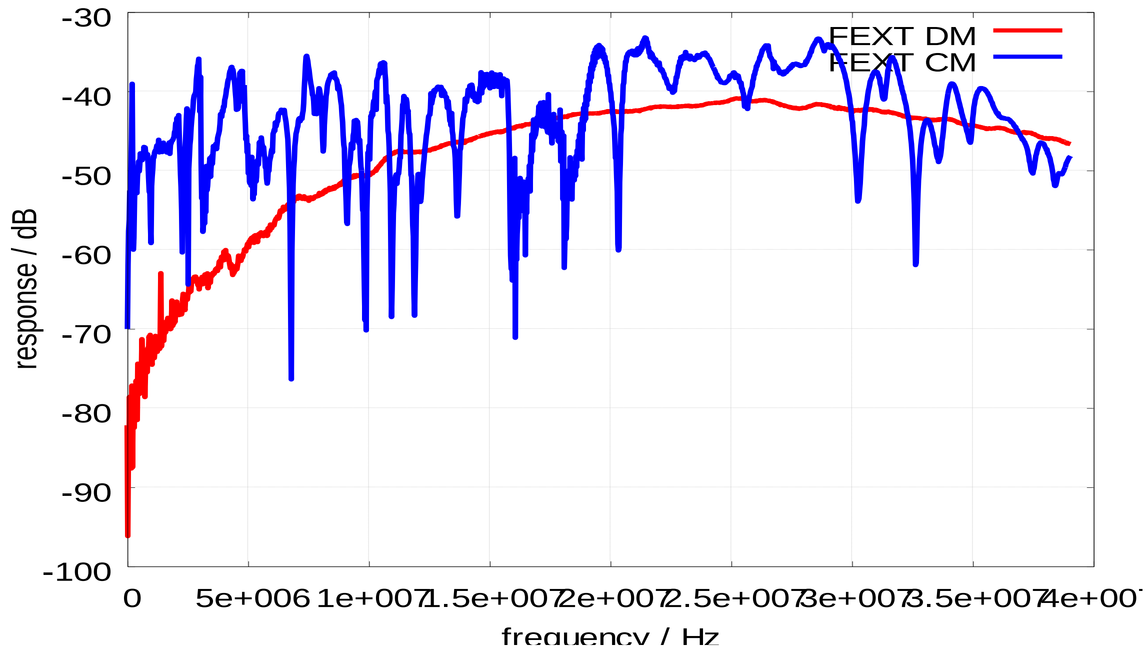
- -40dB
- signal coupling into CM is really small
- no need to worry about cancelation



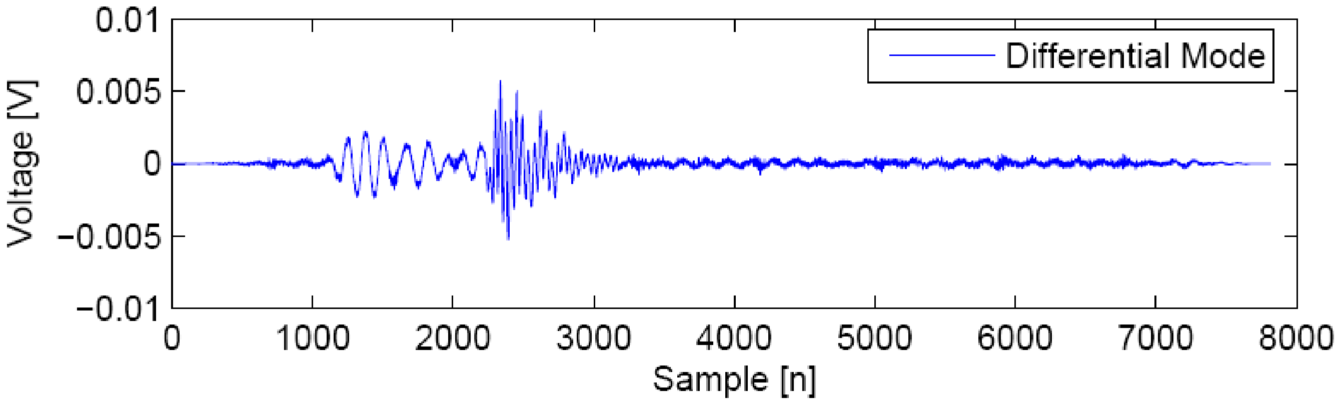
NEXT & FEXT

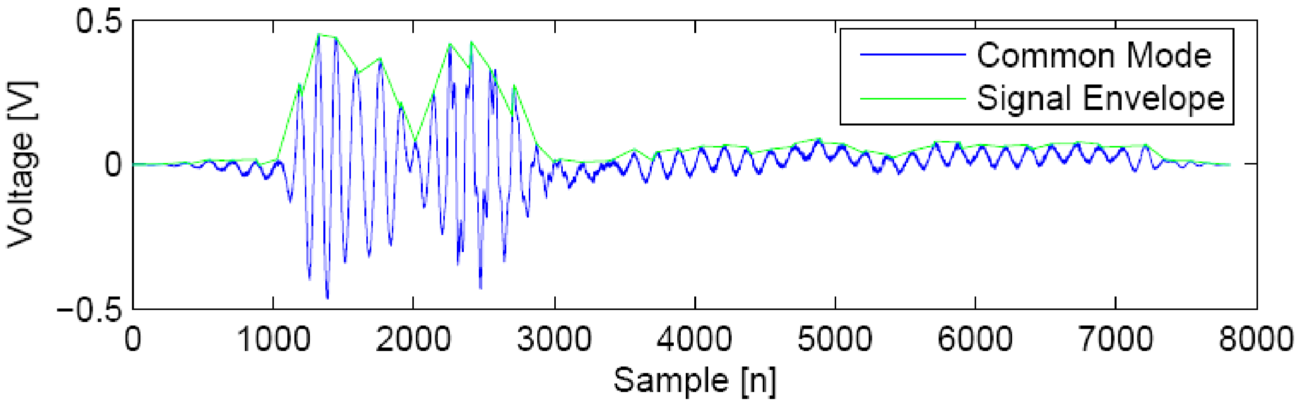
Both NEXT and FEXT couple into CM higher than into DM





Impulse noise detection

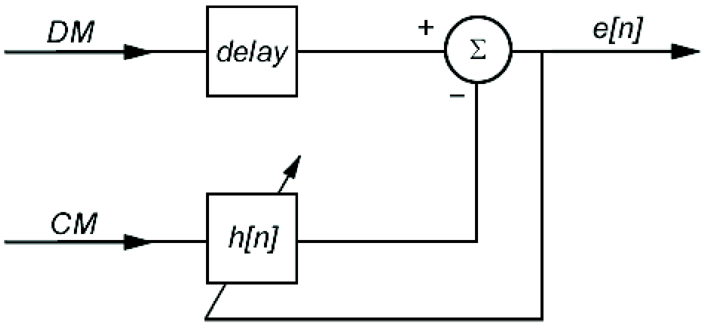




- no desired signals
- adaptation desired only when threshold exceeded
- impulses saved in blocks of size N for convenience
- each block split into non-overlapping sub-blocks
- local maximum in each sub-block
- linear interpolation of the maxima
- values above a certain threshold flagged as impulse samples

Adaptive filtering - Least Mean Squares

- linear adaptive filtering
- automatic adjustment of weights
such that the square error is minimized
- robust
- sensitive to input
- CM is the reference signal
- DM is the input signal
- inputs stored in tapped delay line



$$\mathbf{h}(n+1) = \mathbf{h}(n) + \mu e^*(n)\mathbf{x}_{CM}(n)$$

$$e(n) = \mathbf{x}_{DM} - \mathbf{h}^H(n) * \mathbf{x}_{CM}(n)$$

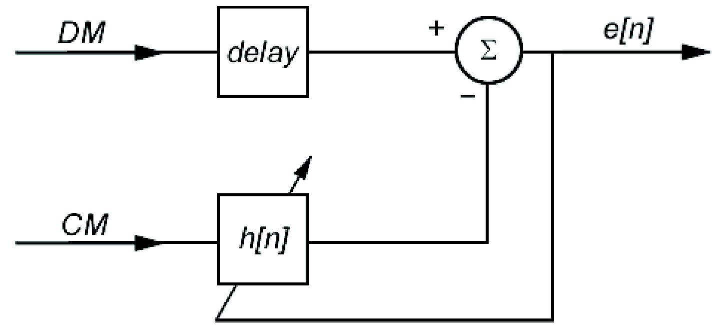
h(n)= current adaptive weights
e(n)=current error
x(n)= current inputs within the tapped delay
μ=step size

NLMS

$$\mathbf{y}(n) = \mathbf{h}^T(n)\mathbf{x}_M(n)$$

$$\mathbf{x}_M(n) = [x(n)\ x(n-1)\ \ldots\ x(n-M+1)]^T$$

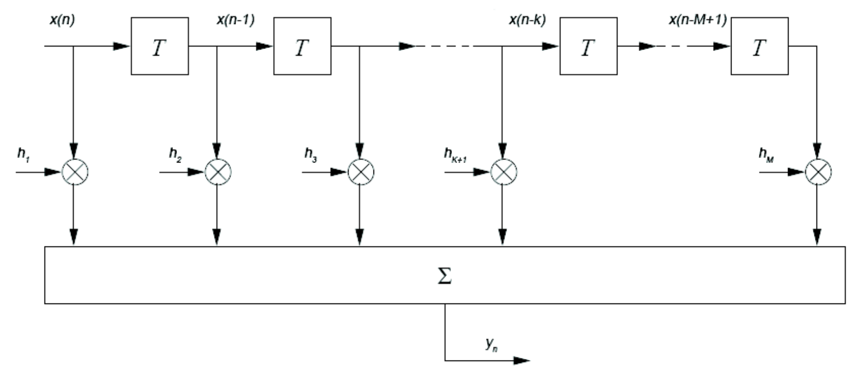
$$\mathbf{h}(n) = [h_1(n)\ h_2(n)\ \ldots\ h_M(n)]^T$$



Update equations

$$\mathbf{h}(n+1) = \mathbf{h}(n) + \frac{\mu e^*(n)\mathbf{x}_{CM}(n)}{\mathbf{x}_{CM}^H \mathbf{x}_{CM}}$$

$$e(n) = \mathbf{x}_{DM} - \mathbf{h}^H(n) * \mathbf{x}_{CM}(n)$$



NLMS

Update equations

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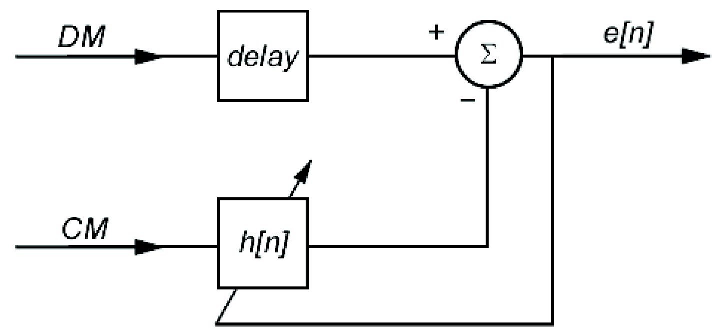
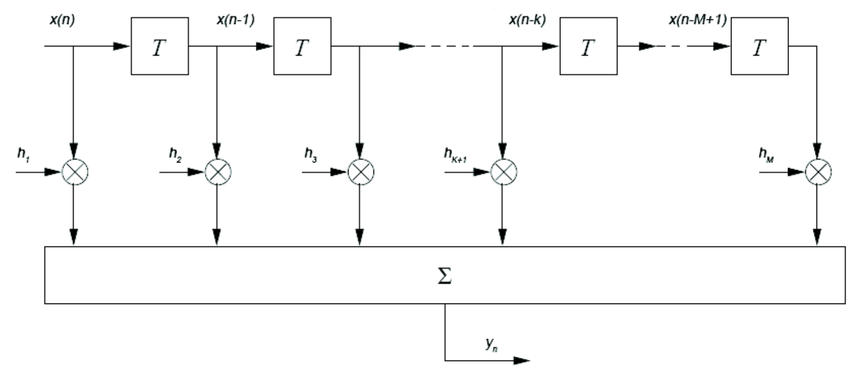


Effect of step size

μ small = slow convergence, stable
μ large= fast convergence, might not be stable



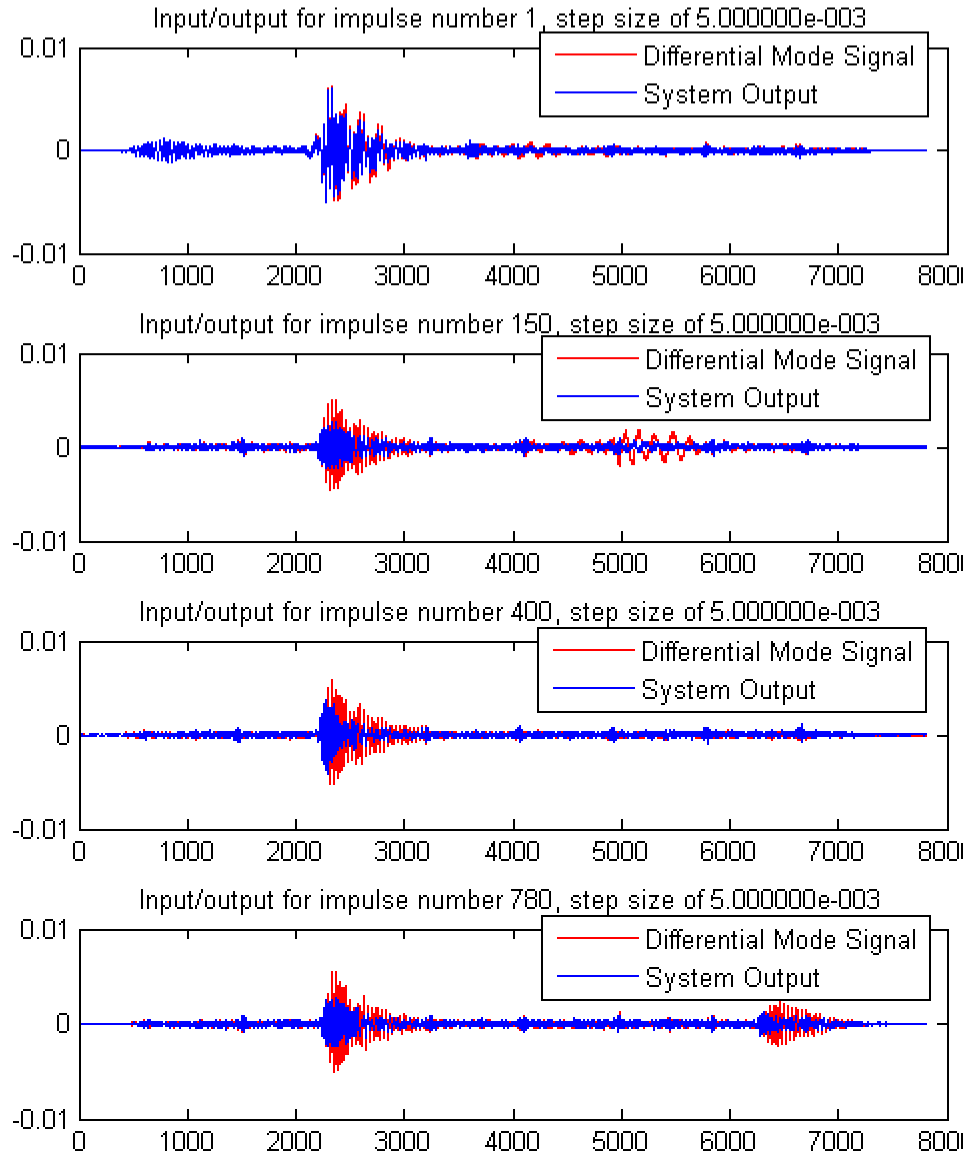
Simulation and Results

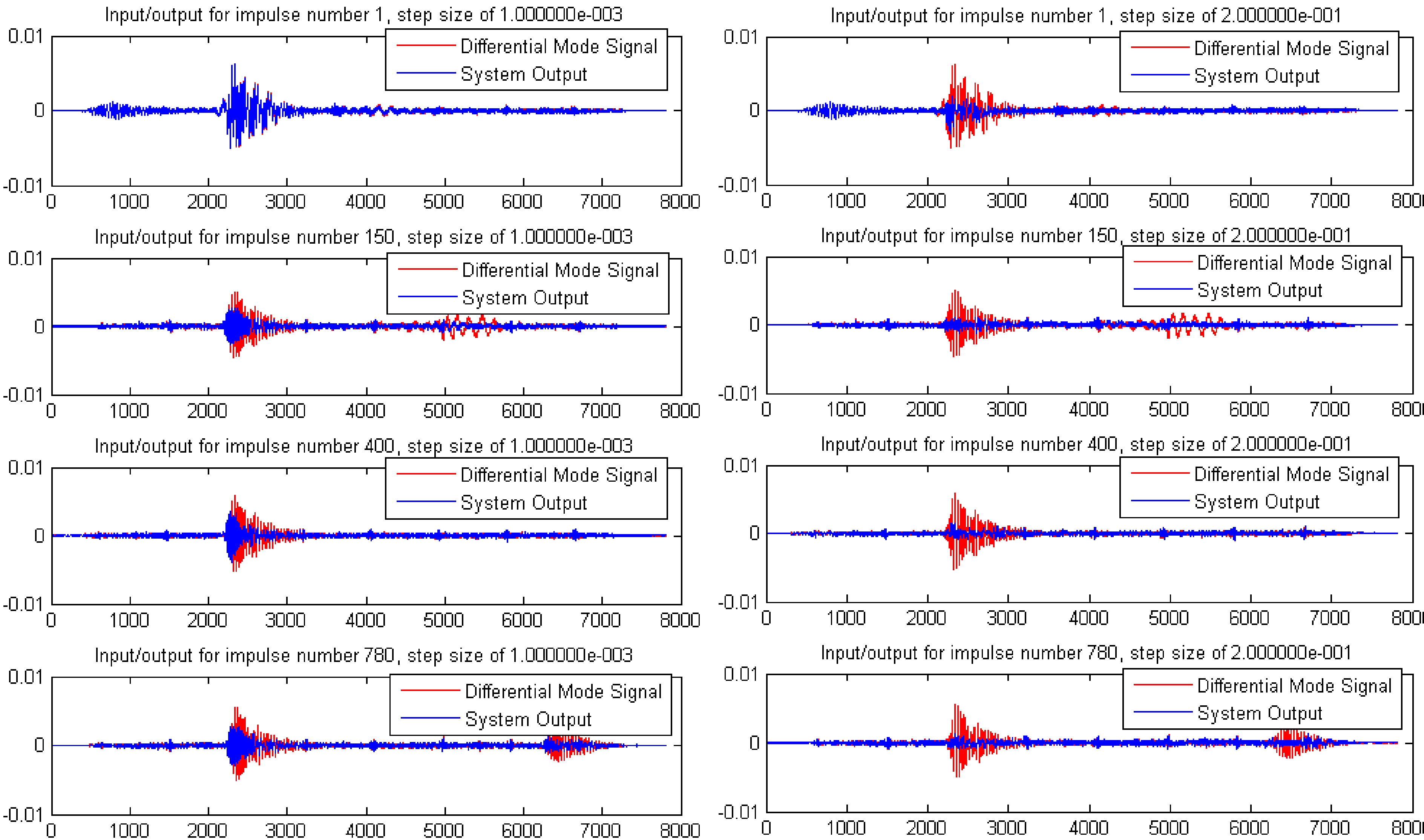
MATLAB simulations

- measurements taken in the Ocean Lab

- impulses which were not generated by a we machine
- peak amplitudes 5mV in DM and 0.5V in CM
- training of the canceler with 780 impulses
- different step sizes used

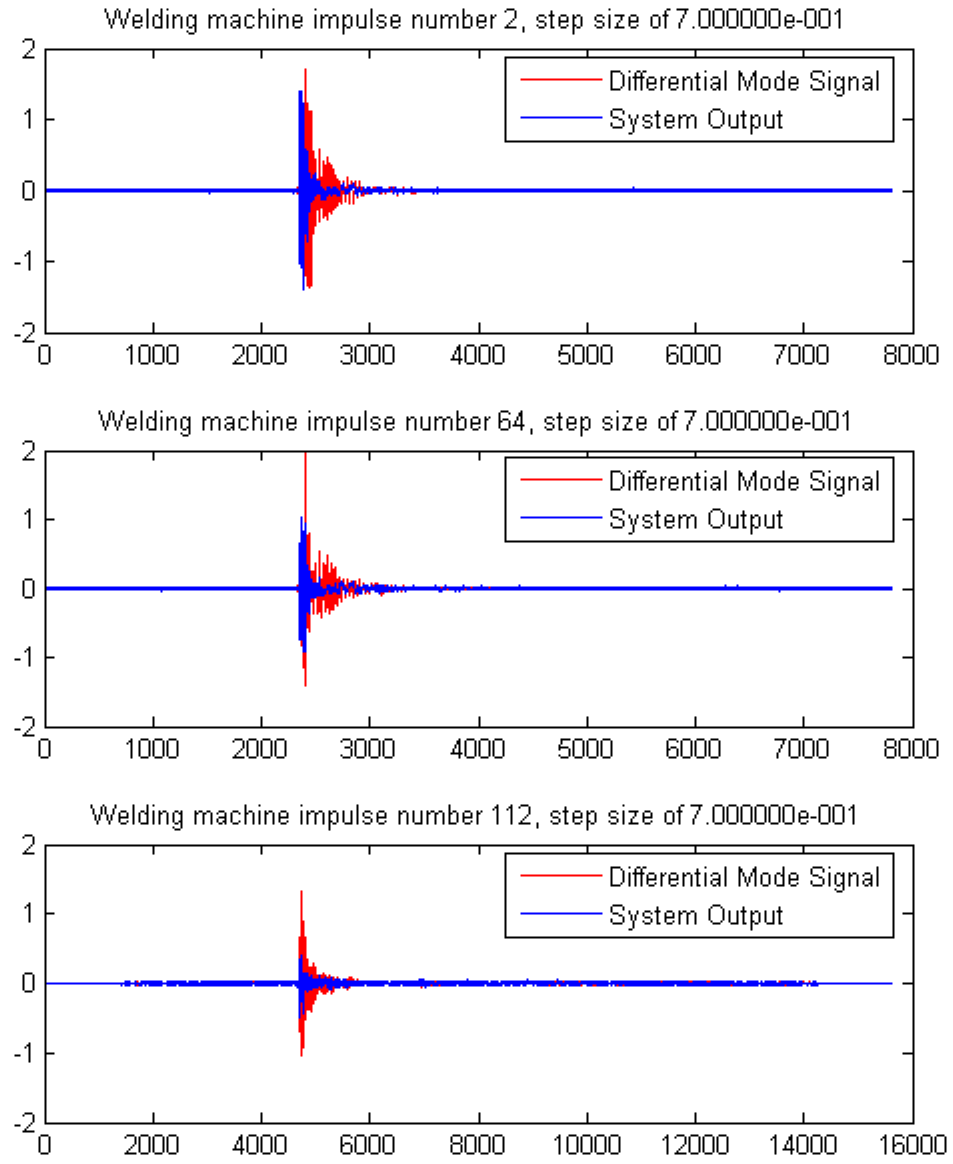
- impulses generated by a welding machine
- peak amplitudes from 0.5V to a few volts in and 10-45V in CM
- training of the canceler with 112 impulses
- different step sizes used

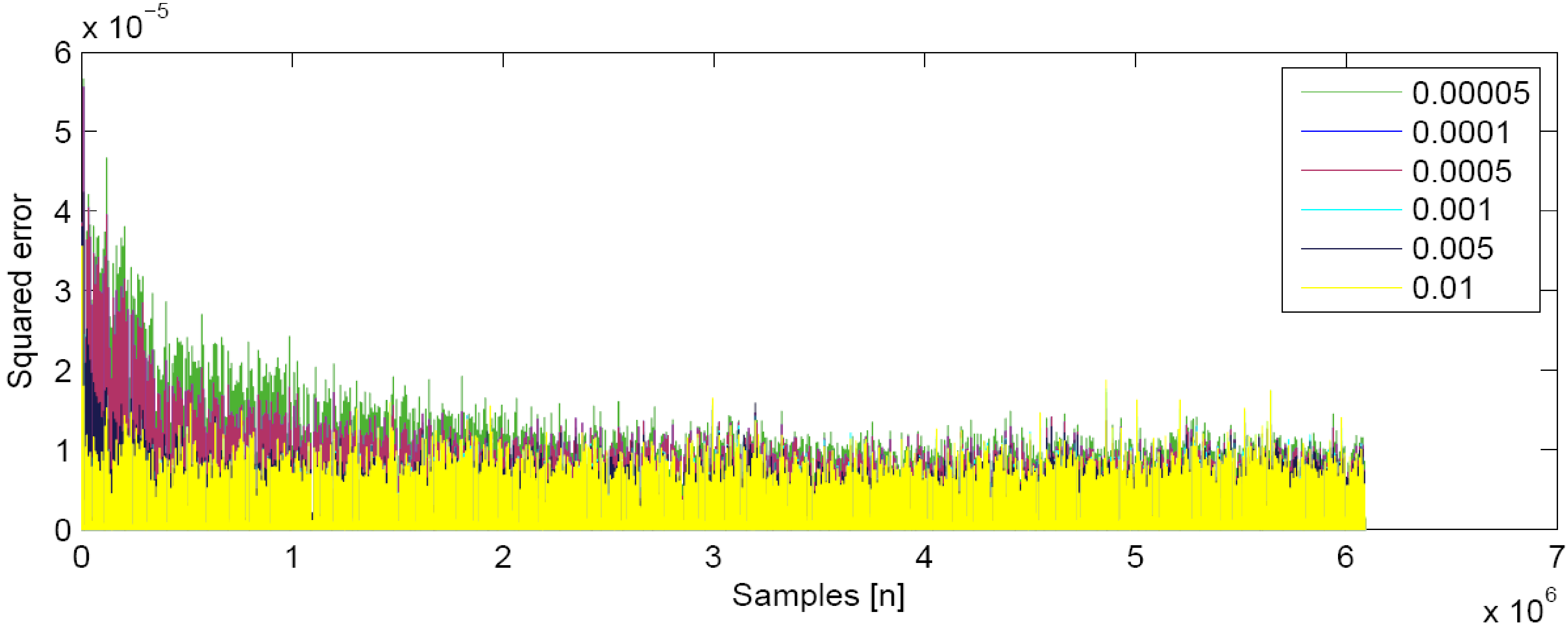


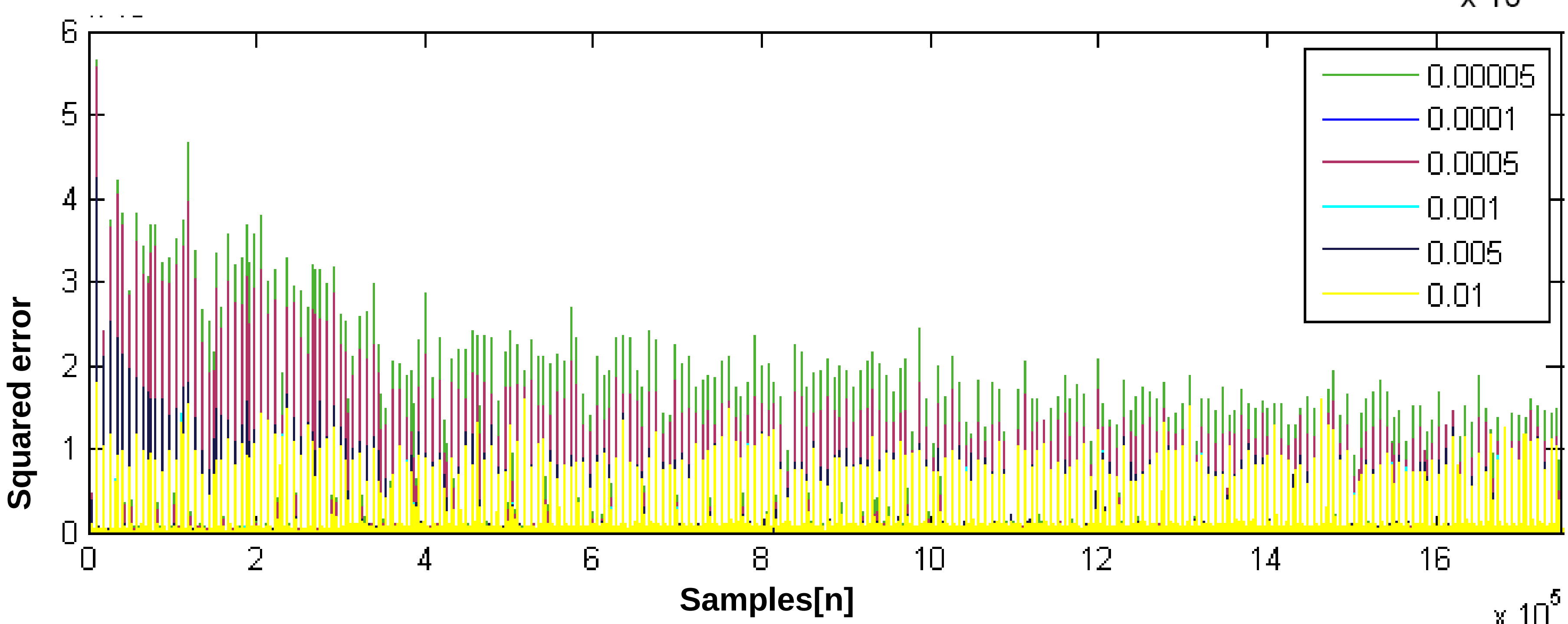

Input/output for impulse number 1, step size of 1.000000e-003
Differential Mode Signal
System Output
0.01
0
-0.01
0
1000
2000
3000
4000
5000
6000
7000
8000
Input/output for impulse number 1, step size of 2.000000e-001
Input/output for impulse number 150, step size of 1.000000e-003
Input/output for impulse number 150, step size of 2.000000e-001
Input/output for impulse number 400, step size of 1.000000e-003
Input/output for impulse number 400, step size of 2.000000e-001
Input/output for impulse number 780, step size of 1.000000e-003
Input/output for impulse number 780, step size of 2.000000e-001

- impulses generated by a welding machine
- cancelation not as nice as in the other case

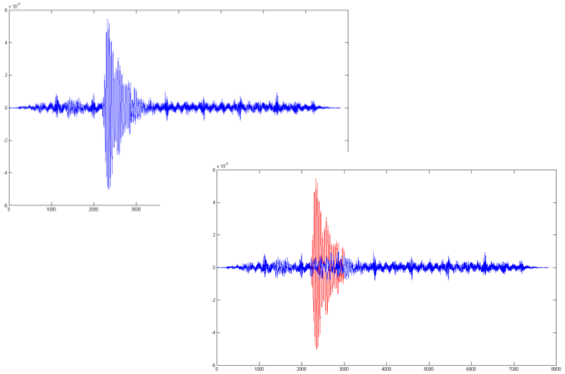
- Reason:
  - not enough available welding impulses to train the canceler (only 112)
  - very high step size had to be used to actually see any change




x 10−5
Squared error
Samples [n]
x 10⁶
0
1
2
3
4
5
6
7
0.00005
0.0001
0.0005
0.001
0.005
0.01


Squared error
Samples[n]
x 10⁵
0
2
4
6
8
10
12
14
16
0.00005
0.0001
0.0005
0.001
0.005
0.01

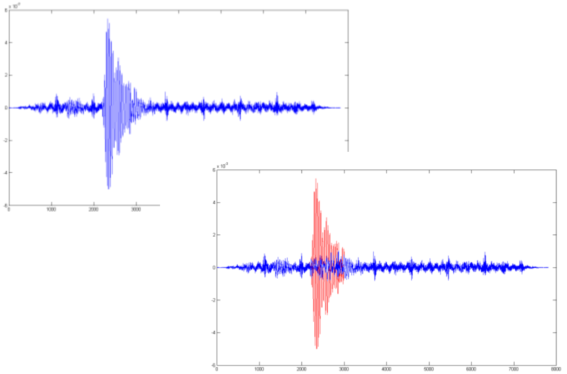
Why this model is a simplification



- impulses not Gaussian distributed
- the interpolation not suited for additional signals
- once the impulse noise positions have been properly detected, the rest of the algorithm can be used

- NEXT and FEXT from adjacent pairs
    - crosstalk from adjacent lines will couple into CM and the canceller will try to adapt for it as well
    - coupling and transfer functions need to be taken into account

References



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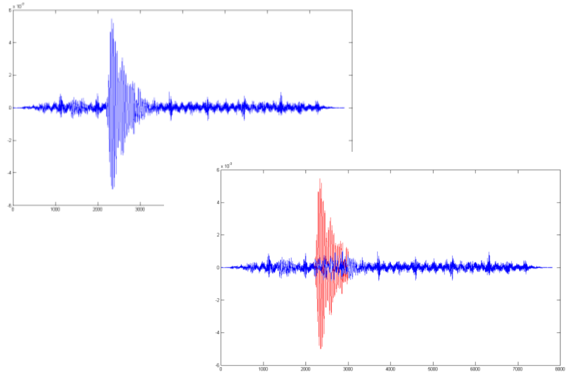

Questions?