Active acoustic time reversal for underwater acoustic barriers

S.M. Jesus and O.C. Rodríguez

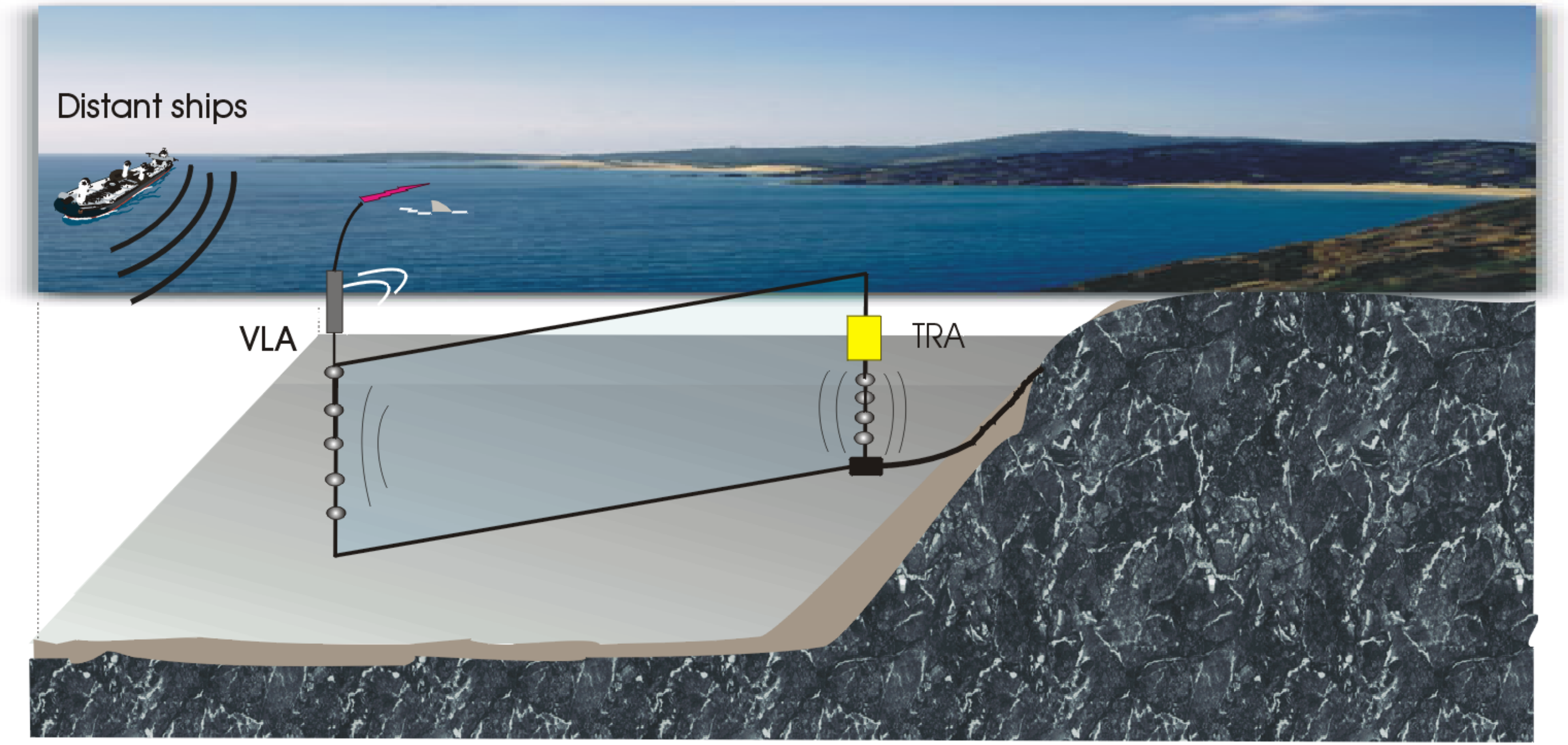
ISR - Institute for Systems and Robotics
University of Algarve, PT-8005-139, Portugal
{sjesus,orodrig}@ualg.pt

June 8, 2007

research funded under projects NUACE and UAB,
programs POSI and POCI, FCT Portugal.

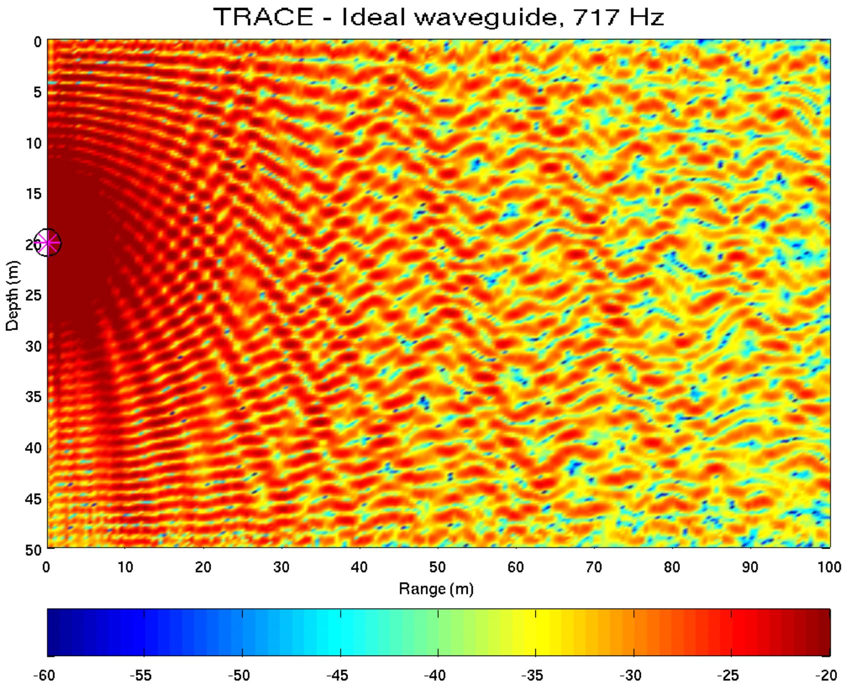
Scenario

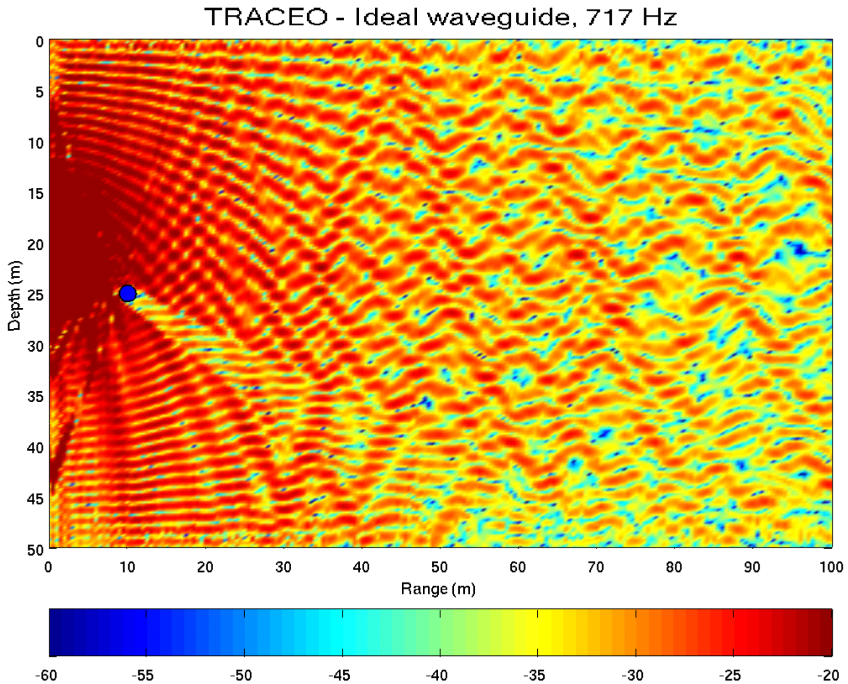
Active acoustic barrier typical scenario



Acoustic propagation

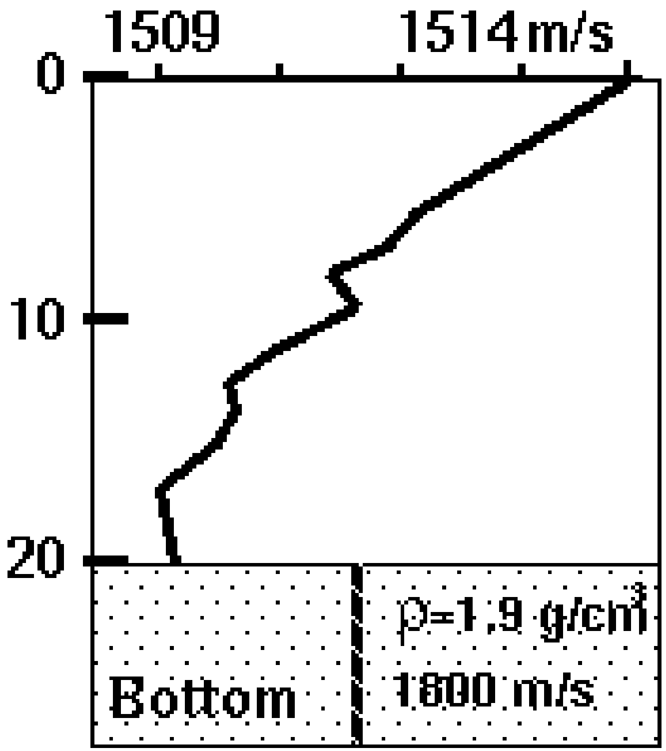
Ideal waveguide, f=717 Hz, rigid object 2 m $\emptyset$

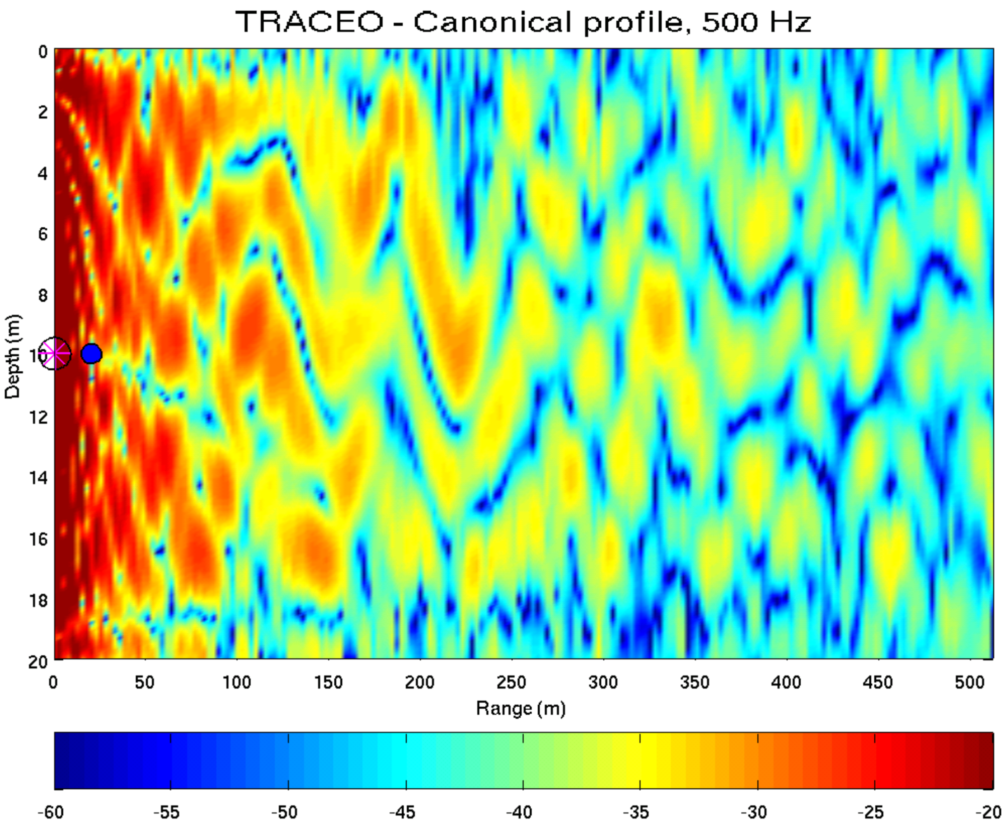




Canonical scenario TL

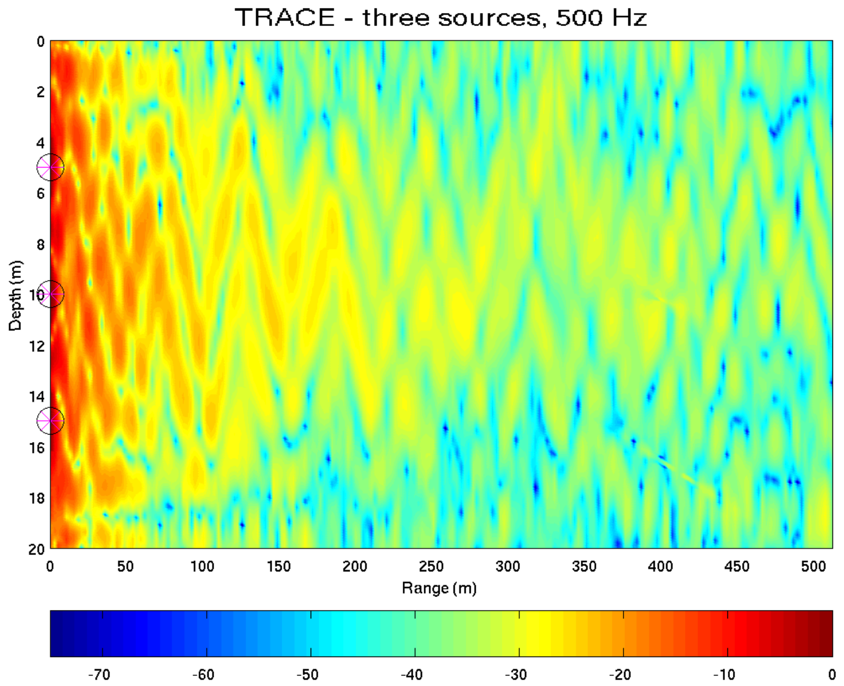
Downward refracting, f=500 Hz, rigid object 1 m $\emptyset$

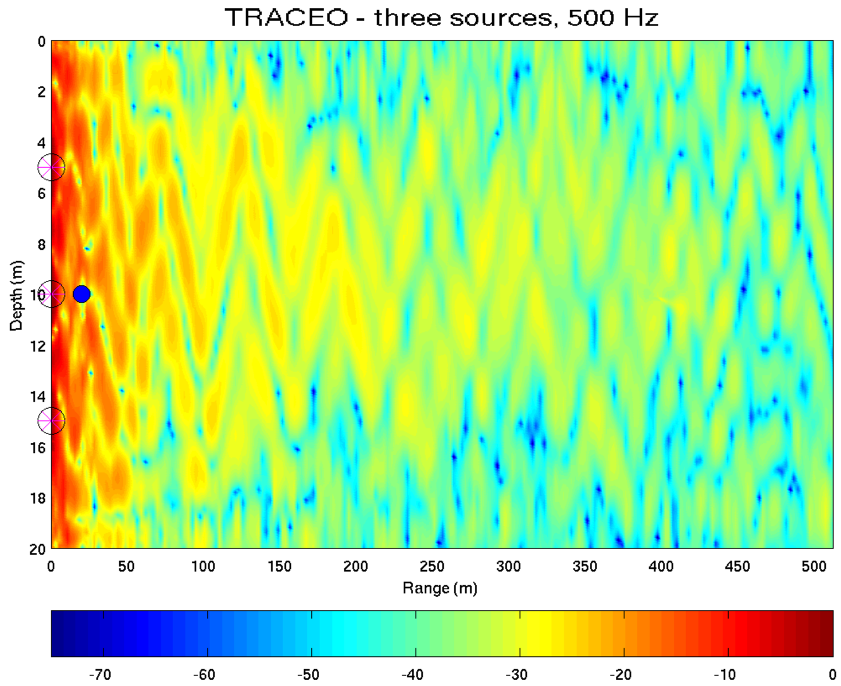




Canonical scenario TL: multiple sources

Downward refracting, f=500 Hz, rigid object 1 m $\emptyset$





Active target detection: binary hypothesis testing

Received signal model:

$$y_k(n) = \mathbf{h}_k(n)\mathbf{s} + w_k(n), \qquad k = 1, \ldots, K, \qquad n = 0, \ldots, N-1$$

deterministic signal, AWGN $w_k(n) : \mathcal{N}(0, \sigma^2)$

Multidimensional data set: (time $\times$ space)

$$\mathbf{y}_a = \mathbf{H}_a\mathbf{s} + \mathbf{w}_a$$

Binary hypothesis testing

H_0: there is no change in the received signal, $\mathbf{y}_a = \mathbf{H}_a\mathbf{s} + \mathbf{w}_a$

H_1: the received signal has changed, $\mathbf{y}_a = \tilde{\mathbf{H}}_a\mathbf{s} + \mathbf{w}_a$

Optimal detector

Likelihood ratio

$$l(\mathbf{y}_a) = \frac{p(\mathbf{y}_a/H_1)}{p(\mathbf{y}_a/H_0)} \geq \gamma$$

Detection statistic

$$L_t(\mathbf{y}_a) = \sum_{n=0}^{N-1} [\mathbf{y}^T(n)\tilde{\mathbf{H}}(n)\mathbf{s} - \mathbf{y}^T(n)\mathbf{H}(n)\mathbf{s}] \geq \gamma'$$

$$L_s(\mathbf{y}_a) = \sum_{k=1}^{K} [\mathbf{y}_k^T\tilde{\mathbf{H}}_k\mathbf{s} - \mathbf{y}_k^T\mathbf{H}_k\mathbf{s}] \geq \gamma'$$

Optimal detector performance

Probability of detection and false alarm

$$P_D = Q\left[\frac{\gamma' - (\epsilon_{\tilde{x}} - \epsilon_{x\tilde{x}})}{\sqrt{\sigma^2 \epsilon_{x-\tilde{x}}}}\right]$$

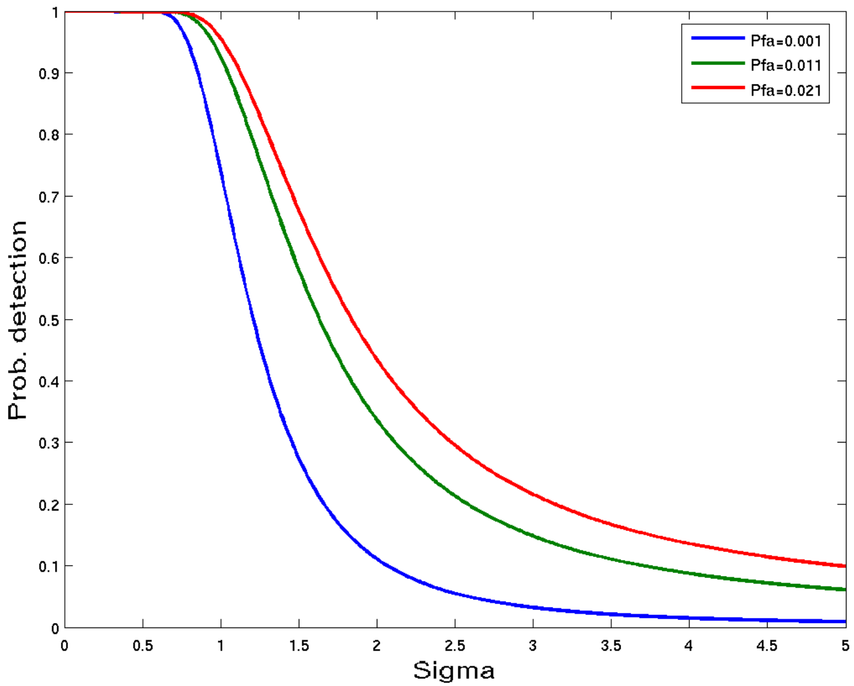
$$P_{FA} = Q\left[\frac{\gamma' - (\epsilon_{x\tilde{x}} - \epsilon_{x})}{\sqrt{\sigma^2 \epsilon_{x-\tilde{x}}}}\right]$$

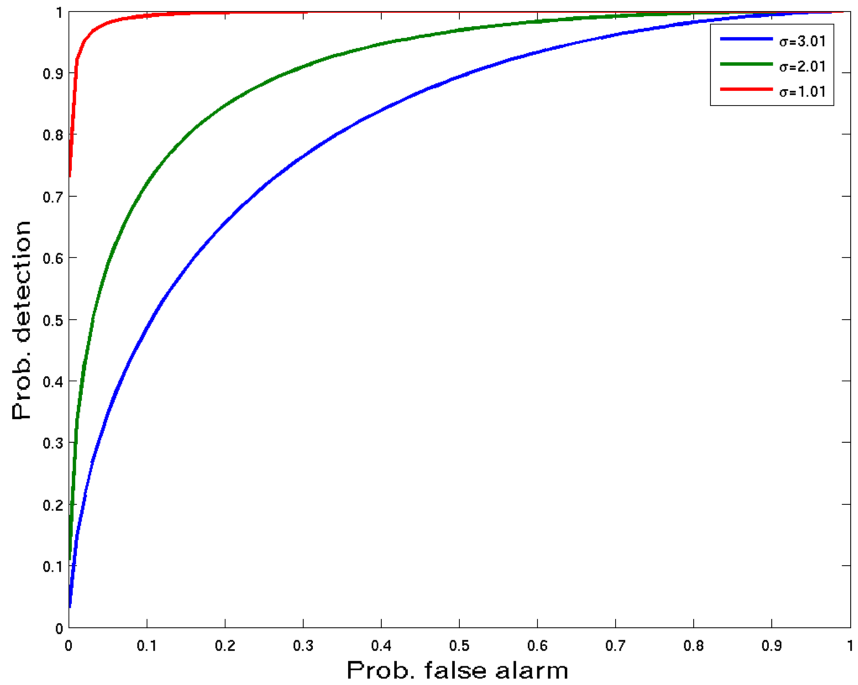
$$P_D = Q\left[Q^{-1}(P_{FA}) - \sqrt{\epsilon_{x-\tilde{x}}/\sigma^2}\right]$$

where $\epsilon_x = \sum_{n=0}^{N-1} \mathbf{x}^T(n)\mathbf{x}(n)$, is the energy contained in signal $x(n)$, received on the K-sensor array in the time interval $[0, N-1]$.

Simulation results: optimal detector performance (1)

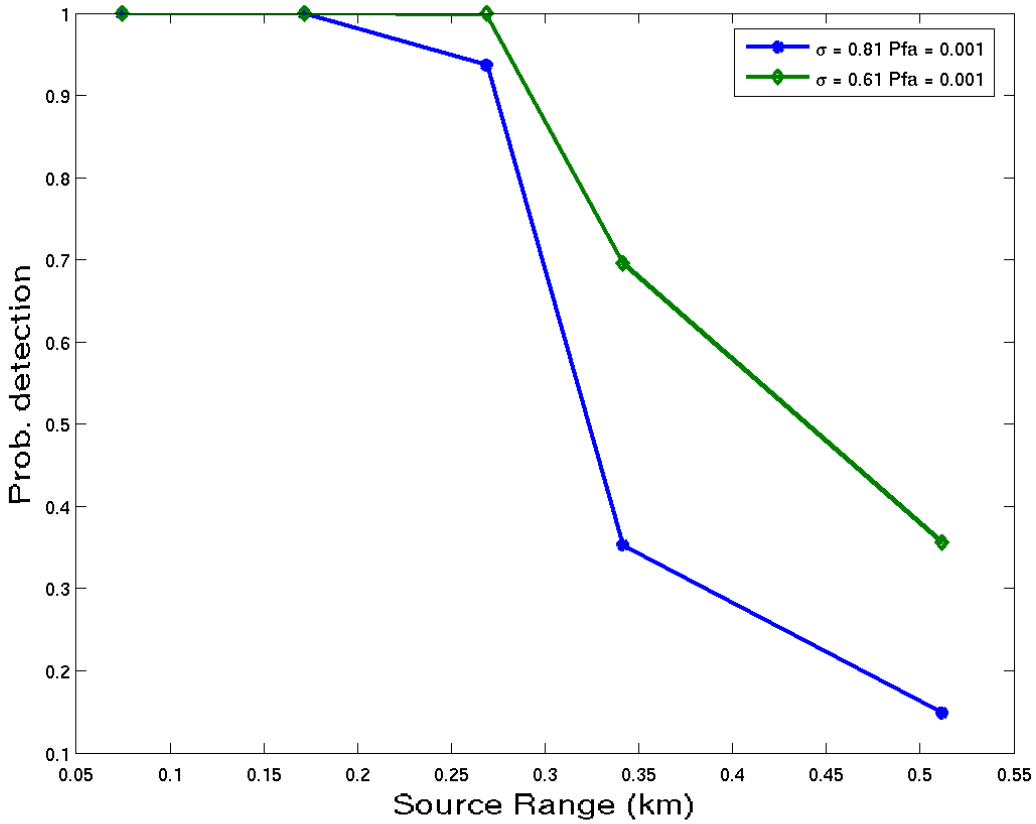
L=16, K=10, SR=270 m, F=5 kHz, BW=100 Hz, cylinder 1m∅





Simulation results: optimal detector performance (2)

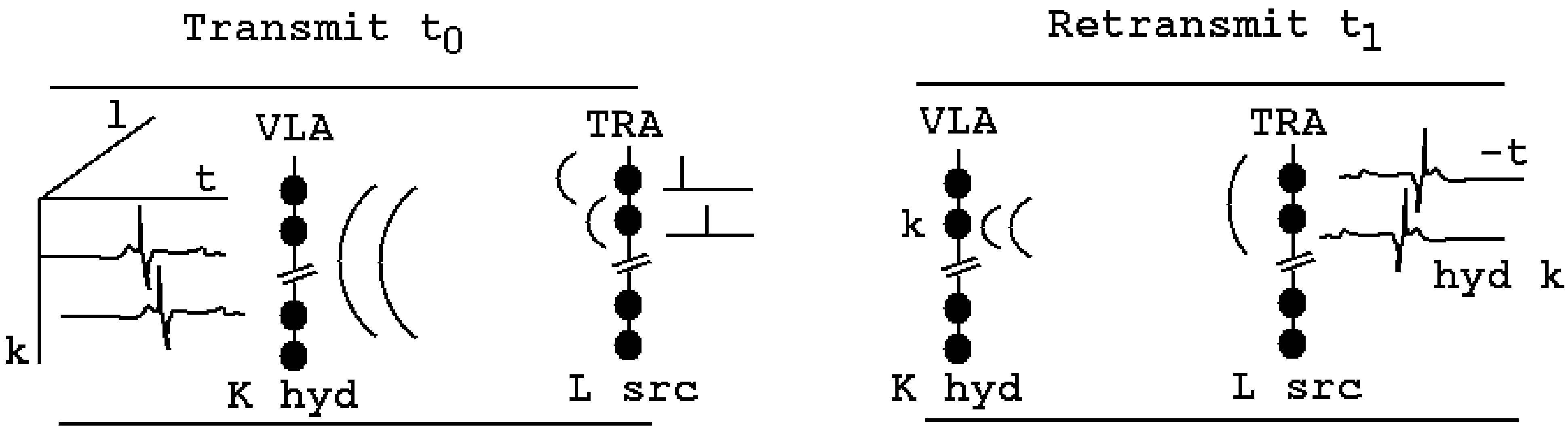
L=16, K=10, Pfa=10^{-3}, F=5 kHz, BW=100 Hz, object 1m∅



Detector implementation: MFP / TR based

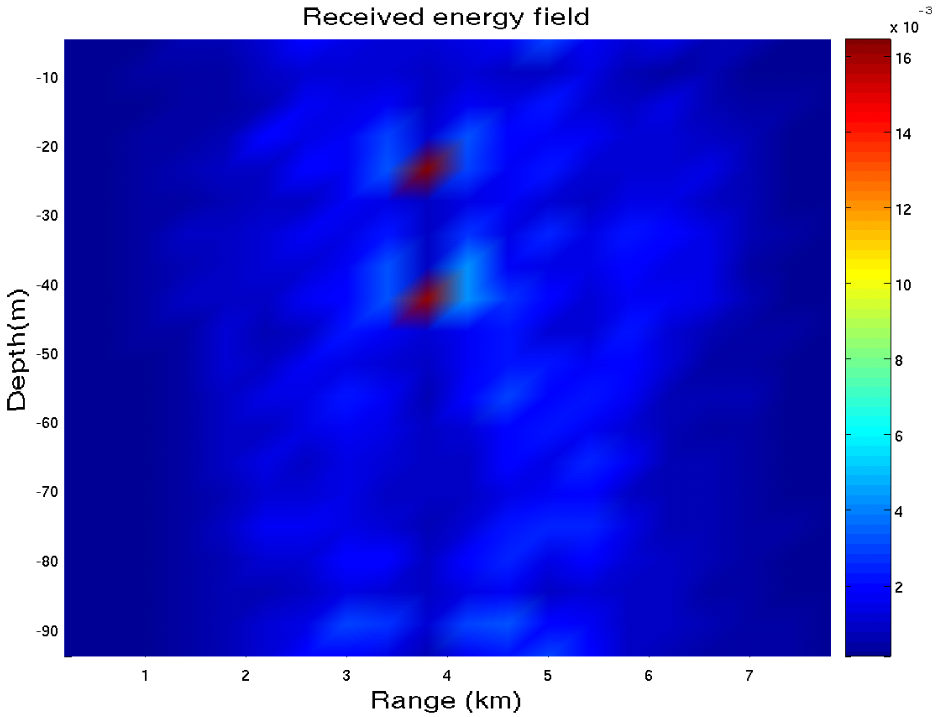
MFP-type: a) invert for acoustic model parameters when no target present
b) use previously inverted parameters for forward search using object at trial locations → estimate of object location

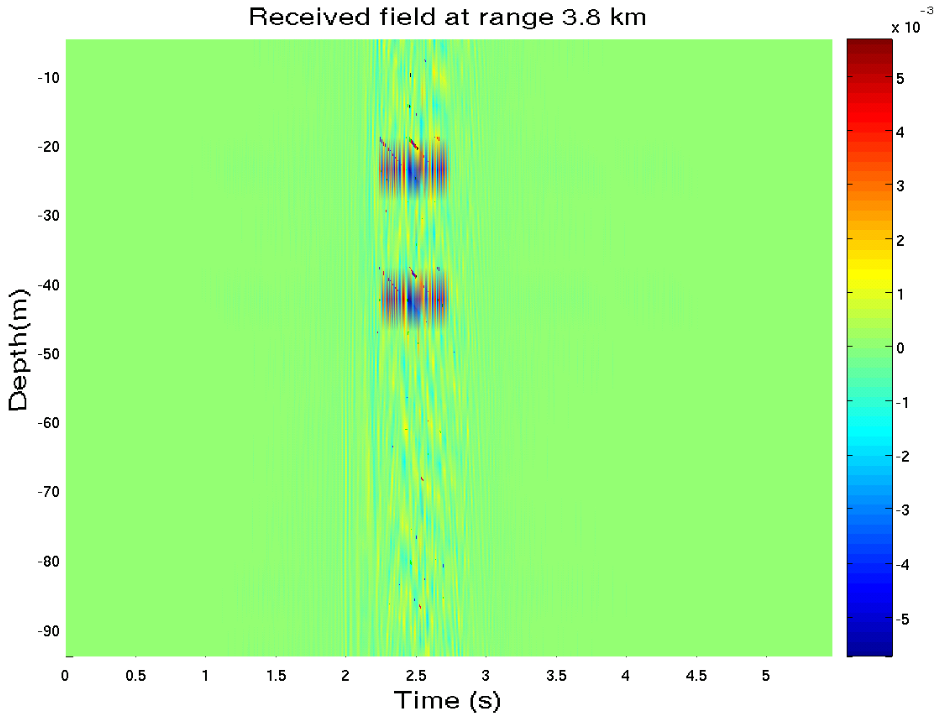
TR-type: realize that $L(\mathbf{y}_a)$ is composed of two matched filter outputs, sampled at time $N-1$.



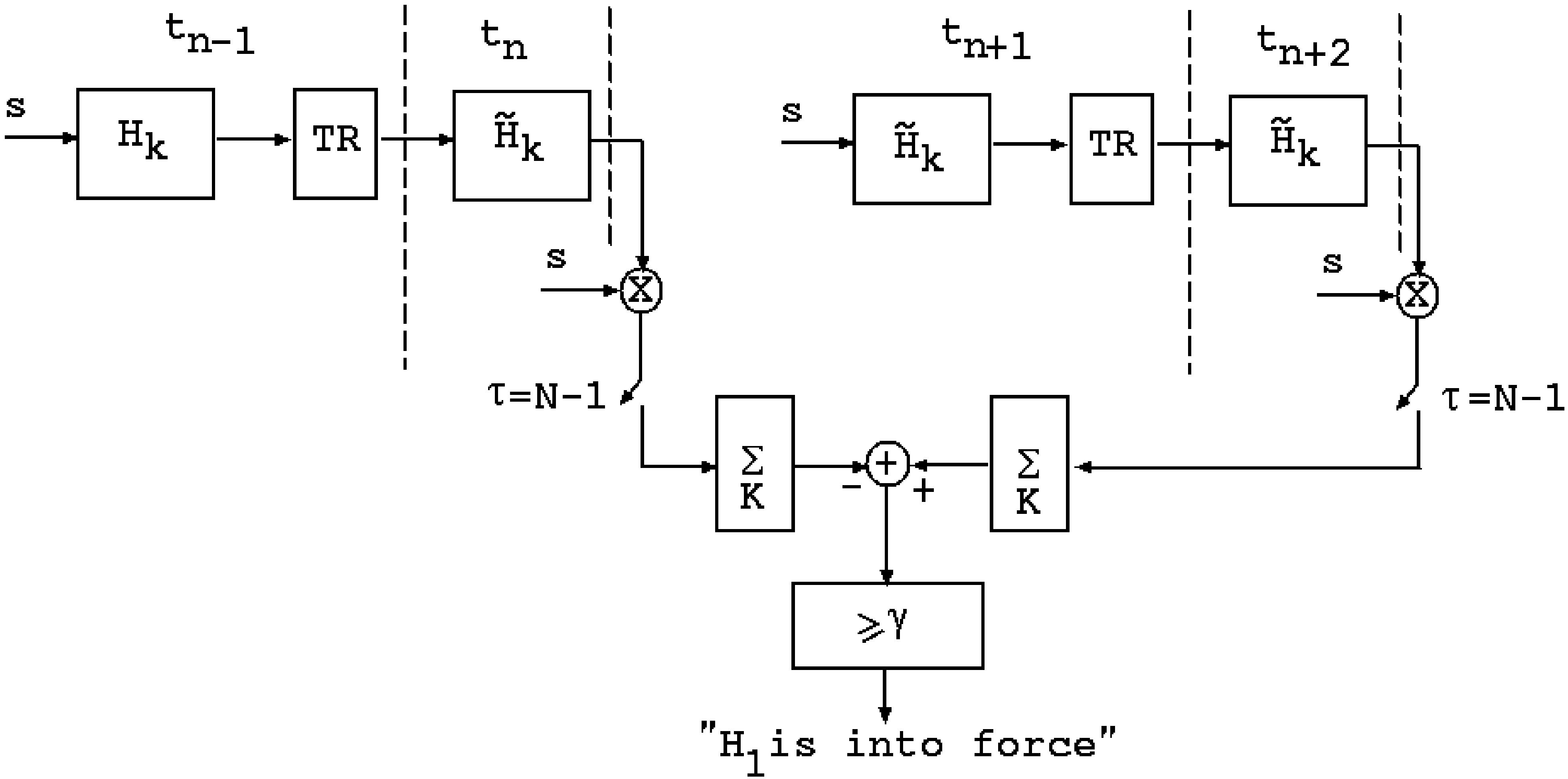
TR multiple focusing example

L=16, K=10 (#3 & #5), SR=3.8 km, F=500 Hz, BW=100 Hz



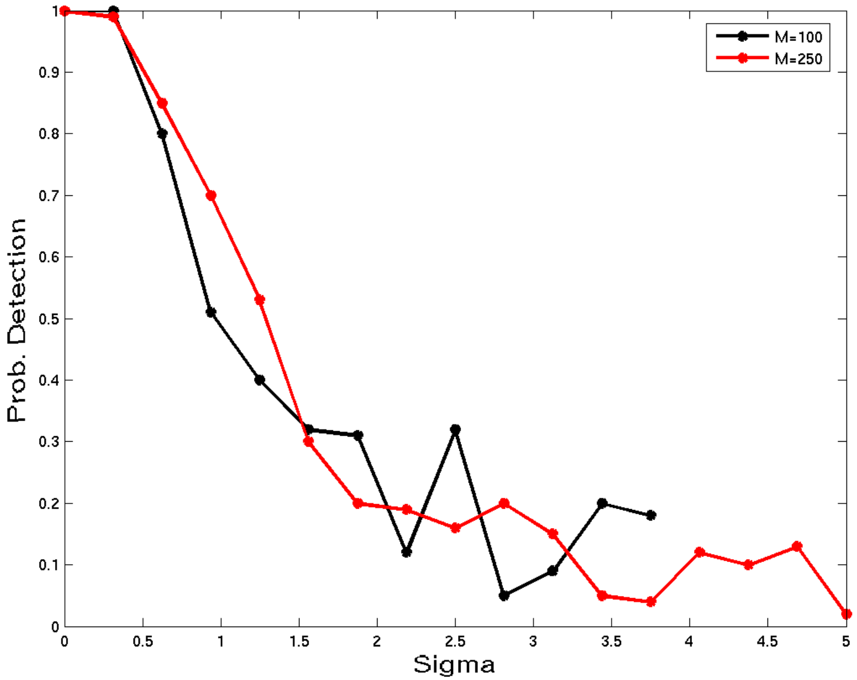


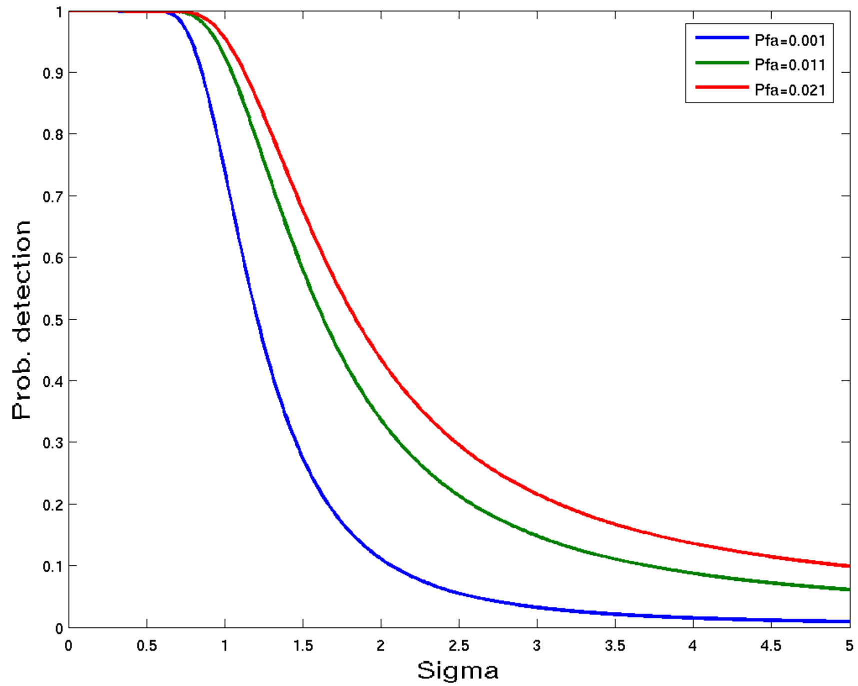
TR implementation



Detector performance: TR vs. optimal

L=16, K=10, Pfa=10^{-3}, F=5 kHz, BW=100 Hz, object 1m∅





Conclusions and perspectives

Conclusions

- TR allows for a near optimal detector implementation
- the forward field has enough structure for detection
- TRACE/TRACEO forward scattering modelling tool

(near) Future work

- test in real conditions: 8 transducers, 16 hydrophones (2-16 Sep 2007, Hopavagen Bay, Trondheim, Norway)
- include backscatter on TRA
- study the target approach to the barrier