

# Estimation of thermo-hydrodynamic parameters in energy production systems using non-stationary signal processing

F.-M. Birleanu\* - C. Ioana\* - A. Serbanescu\*\* - G. Serban\*\*\* - E. Sofron\*\*\*

(\*): GIPSA-lab, Images-Signal Department, FRANCE

(\*\*): Military Technical Academy, Bucharest, ROMANIA

(\*\*\*): University of Pitesti, ROMANIA



# Outline

- Motivations and Application context
- Physical considerations
- Signal processing framework
- Results
- Conclusion

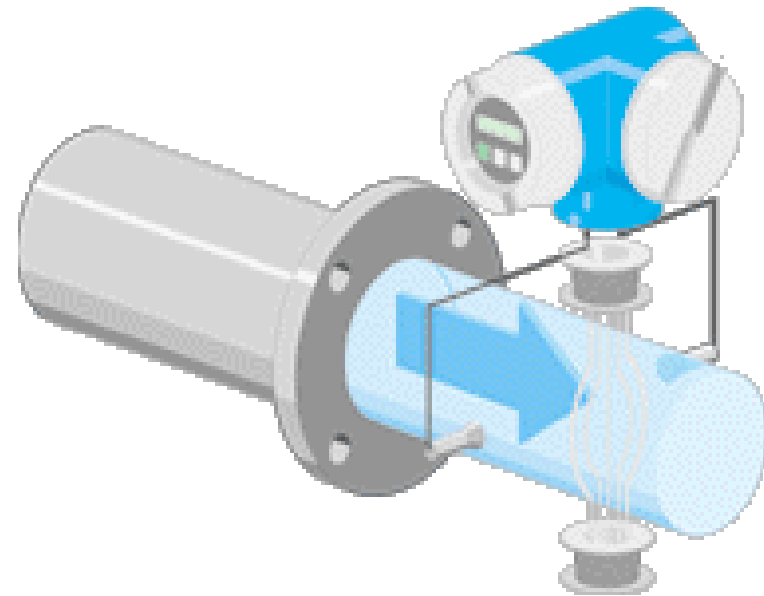
# Motivations and Application context

Estimation of hydraulic parameters of fluid flows (water or gas)



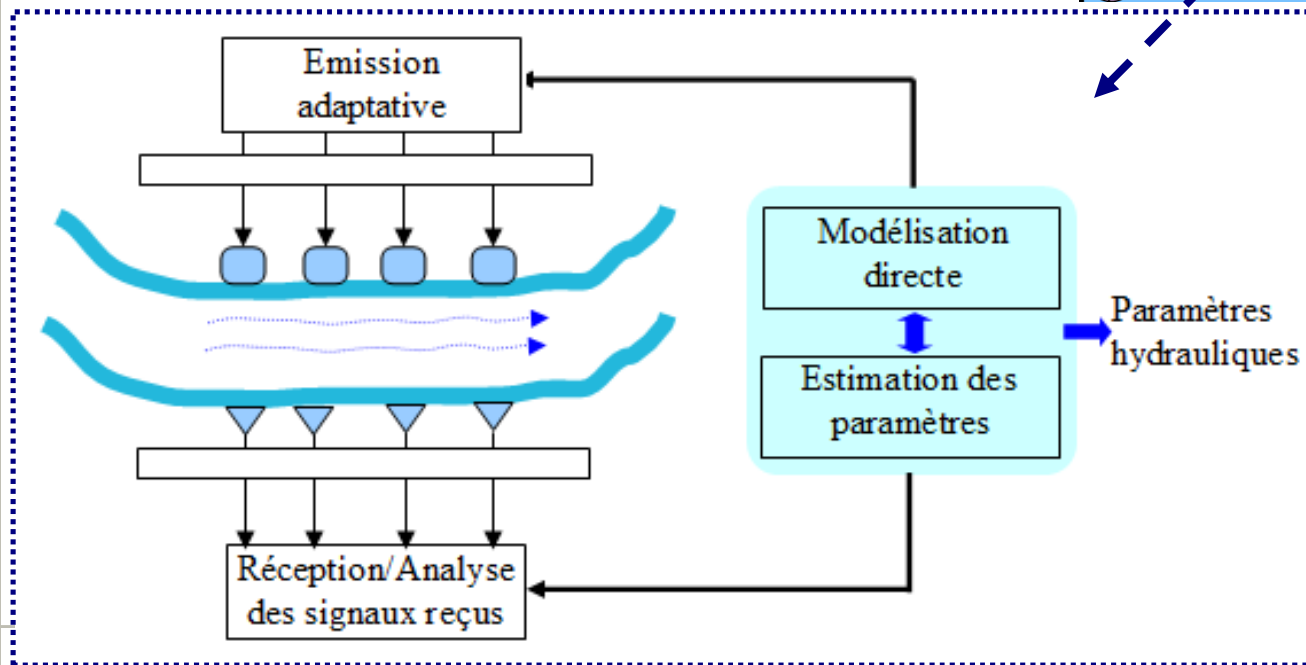
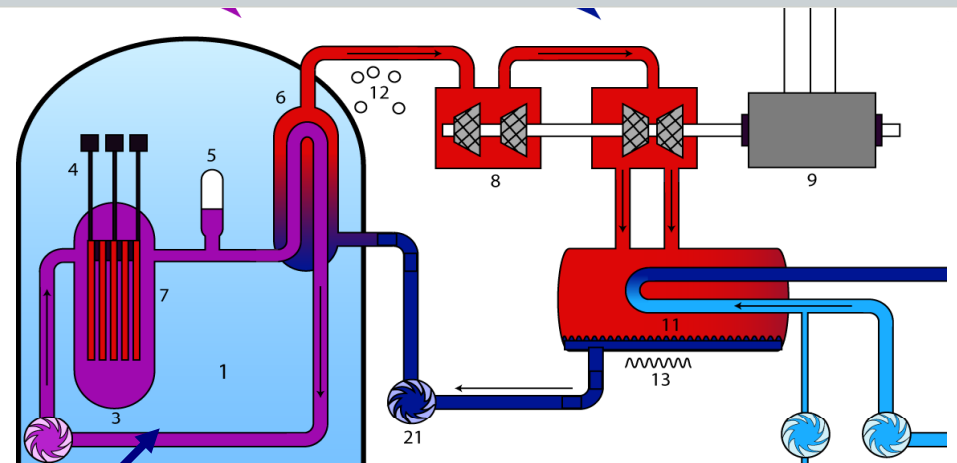
# Motivations and Application context

Current solution – mostly intrusive



# Motivations and Application context

...using non-invasive techniques

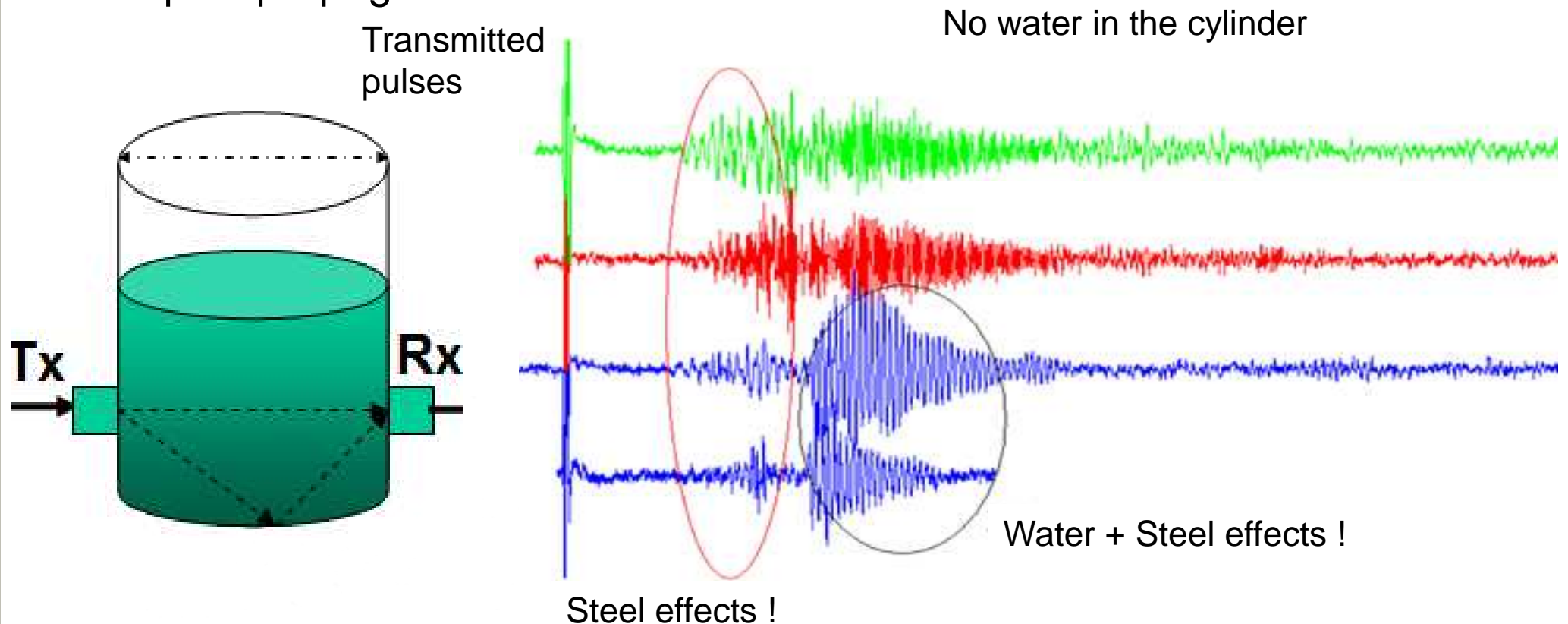




# Motivations and Application context

Difficulties in terms of signal processing

- Complex propagation environments...

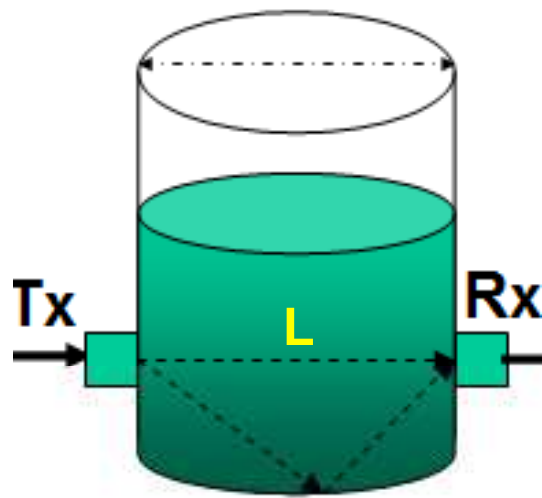


- Connection between signal and physical parameters !

# Outline

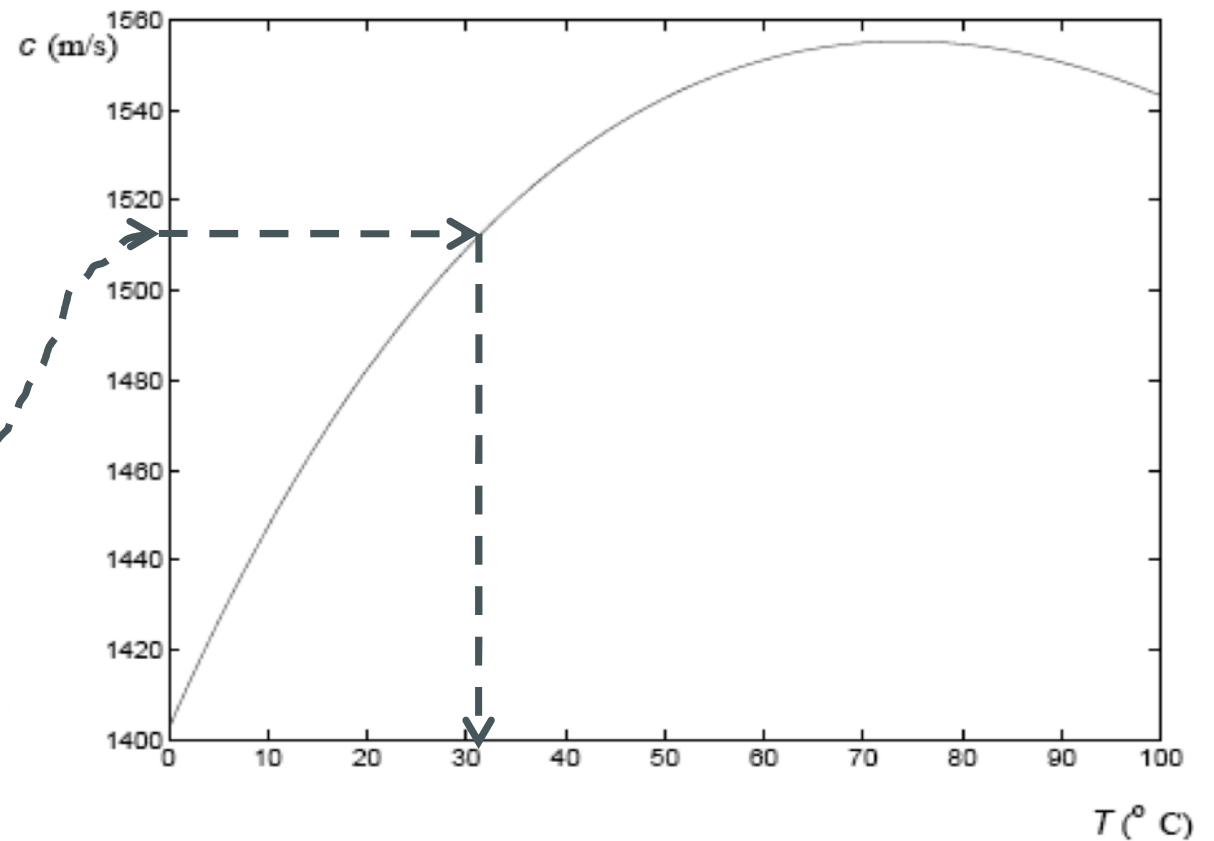
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# Measuring temperature



TOA  
estimation

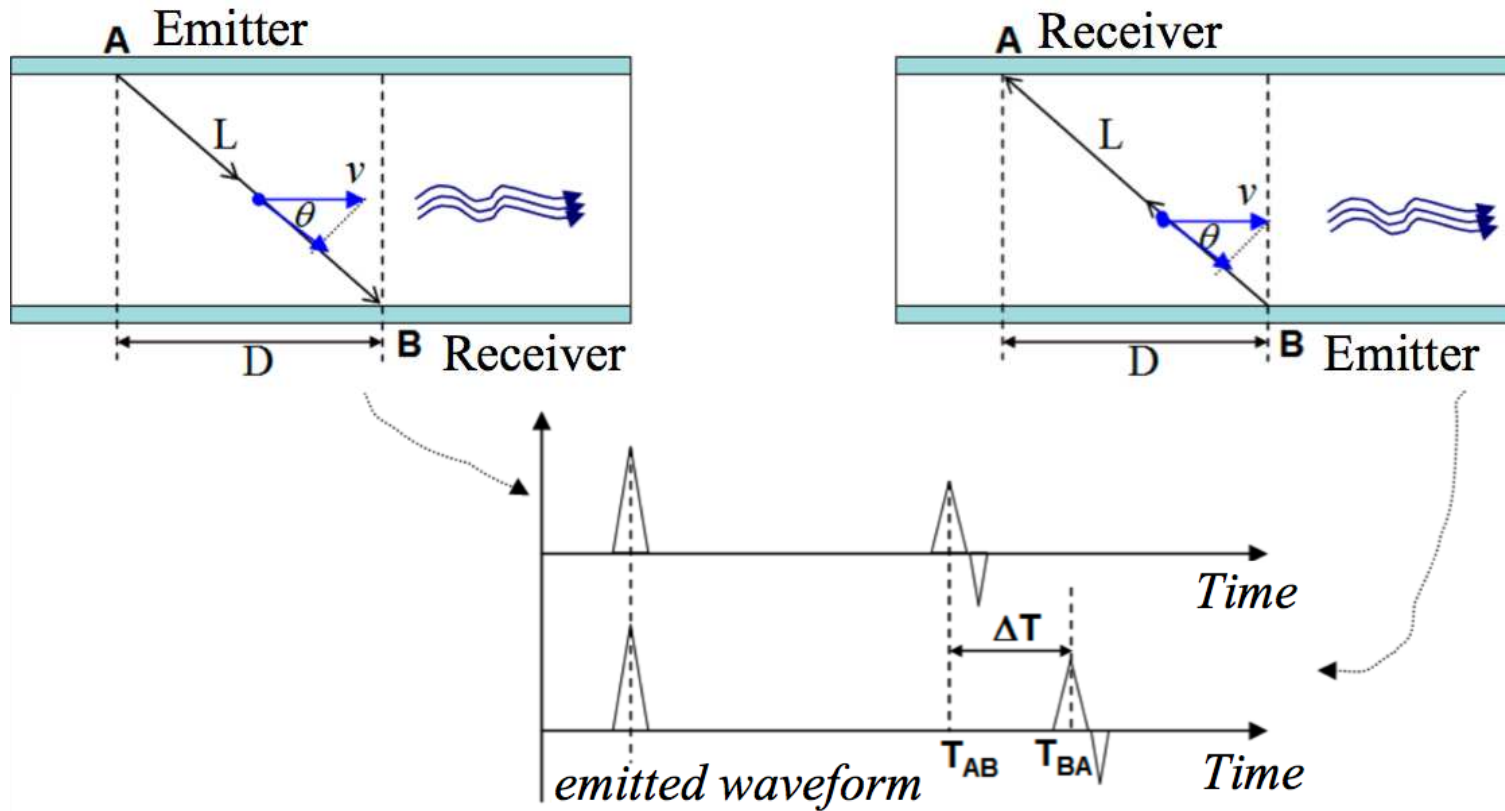
$$\hat{c} = \frac{L}{TOA}$$



$$c = 1.4024 \cdot 10^3 + 5.0384 \cdot T - 5.8114 \cdot 10^{-2} \cdot T^2 + 3.3456 \cdot 10^{-4} \cdot T^3 - 1.4815 \cdot 10^{-6} T^4 + 3.1608 \cdot 10^{-9} \cdot T^5$$



# Measuring flow rate



$$v = \frac{L^2}{2D} \left( \frac{\Delta T}{T_{AB} \cdot T_{BA}} \right); \Delta T = T_{BA} - T_{AB}$$

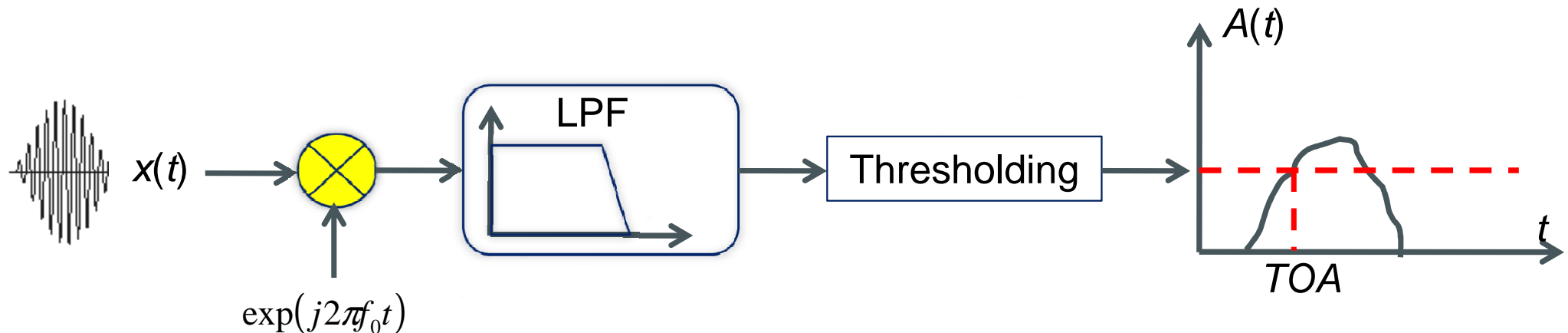
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# Signal Processing Framework

Main topic : Estimation of TOAs (Time of Arrivals)

*One common method (Envelope detector)*

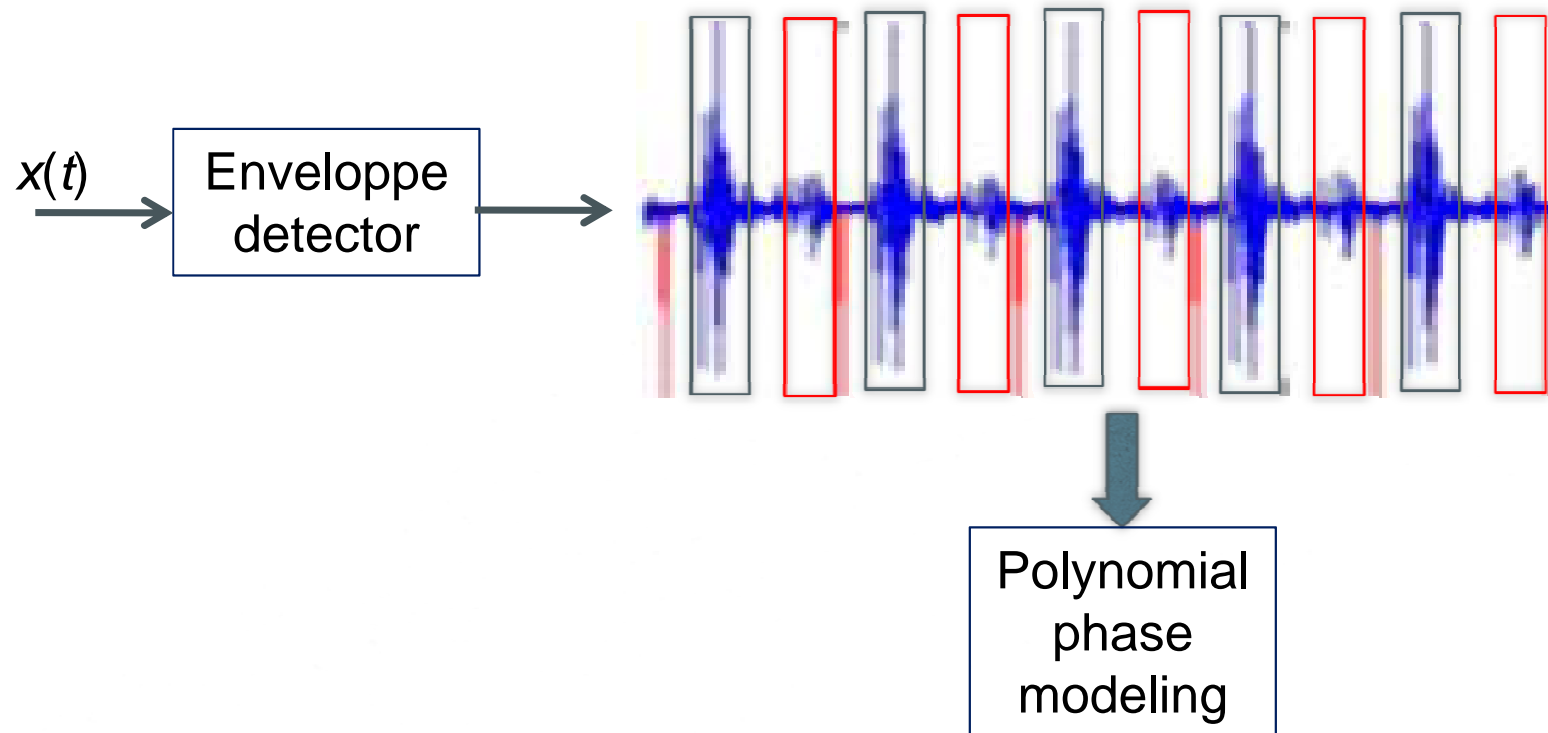


BUT, in our case,  $f_0$  must follow the Doppler effect (induced by the flow)

# Signal Processing Framework

Main topic : Estimation of TOAs (Time of Arrivals)

- Classical detection and Polynomial Phase Modelling



# Signal Processing Framework

**High-Order Ambiguity Function (HAF) = Fourier transform of high-order instantaneous moment**

$$HIM_s^{(1)}(t) = s(t)$$

$$HIM_s^{(2)}(t) = s(t) \cdot s^*(t - \tau)$$

.....

$$HIM_s^{(K)}(t) = HIM_s^{(K-1)}(t) \cdot HIM_s^{(K-1)*}(t - \tau)$$

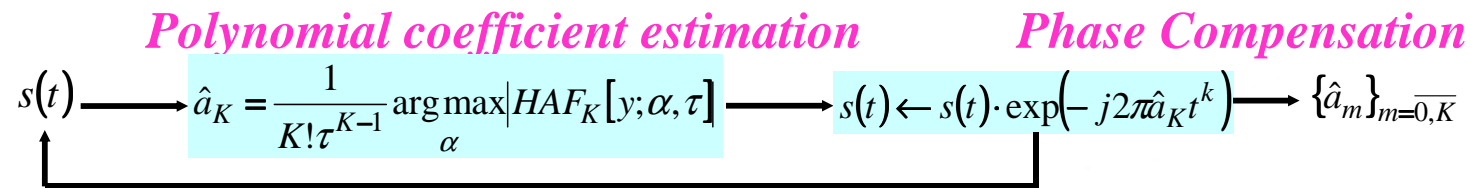
**Main property : the  $k^{th}$  order HAF of a  $k^{th}$  order polynomial phase signal (PPS) is a spectral peak, corresponding to the  $k^{th}$  order polynomial coefficient**

$$HIM_s^{(K)}(t) = \underbrace{A^{2K-1} \exp j(\tilde{\omega}_K \cdot t + \tilde{\phi}_K)}_{\text{Sinusoid}} \xRightarrow{\text{Fourier Transform}} HAF_K[s; \alpha, \tau] = A^{2K-1} e^{j\tilde{\phi}} \delta(\alpha - \tilde{\omega})$$

$$\tilde{\omega}_K = k! \tau^{k-1} a_k \quad \tilde{\phi}_K = (k-1)! \tau^{k-1} a_{k-1} - 0.5k!(k-1)\tau^k a_k$$

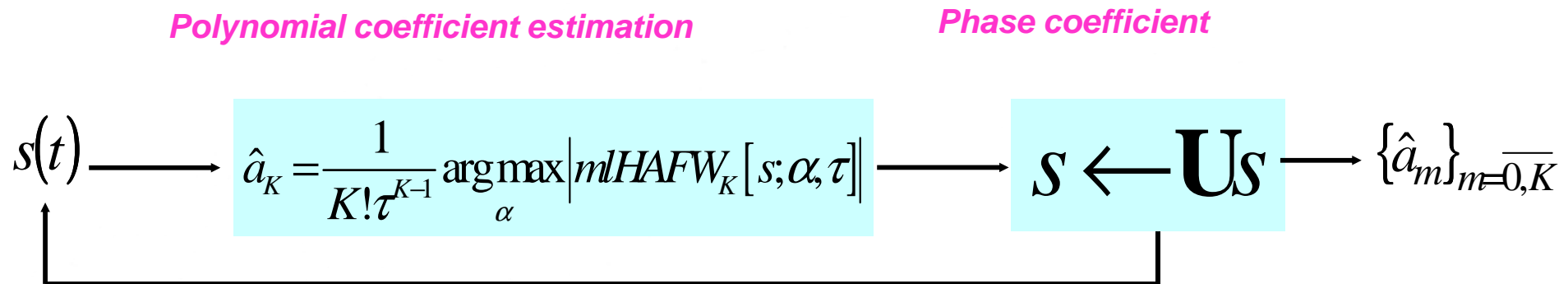
# Signal Processing Framework

- Classical estimation procedure



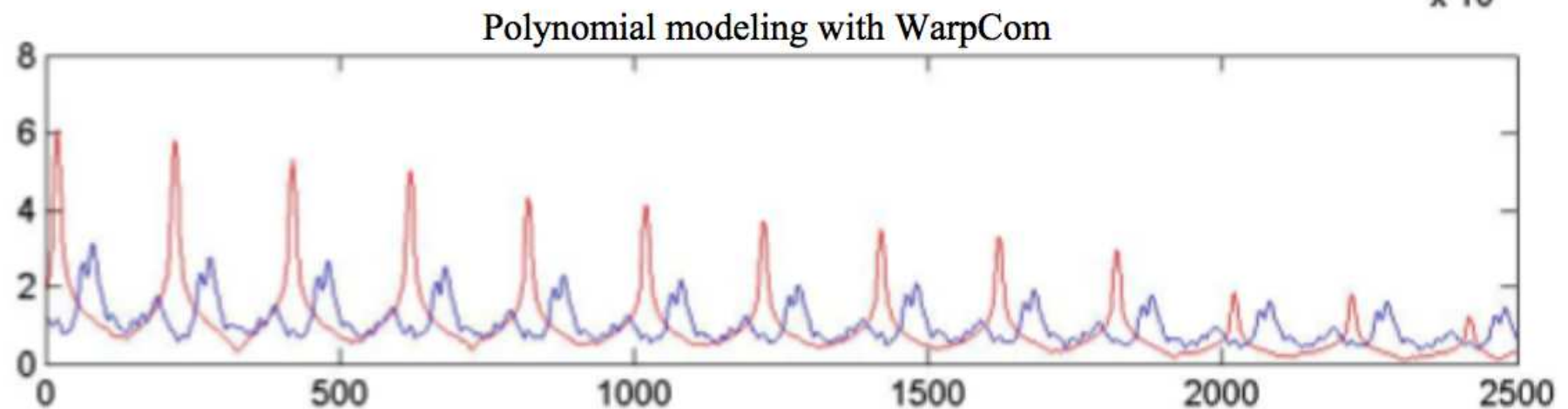
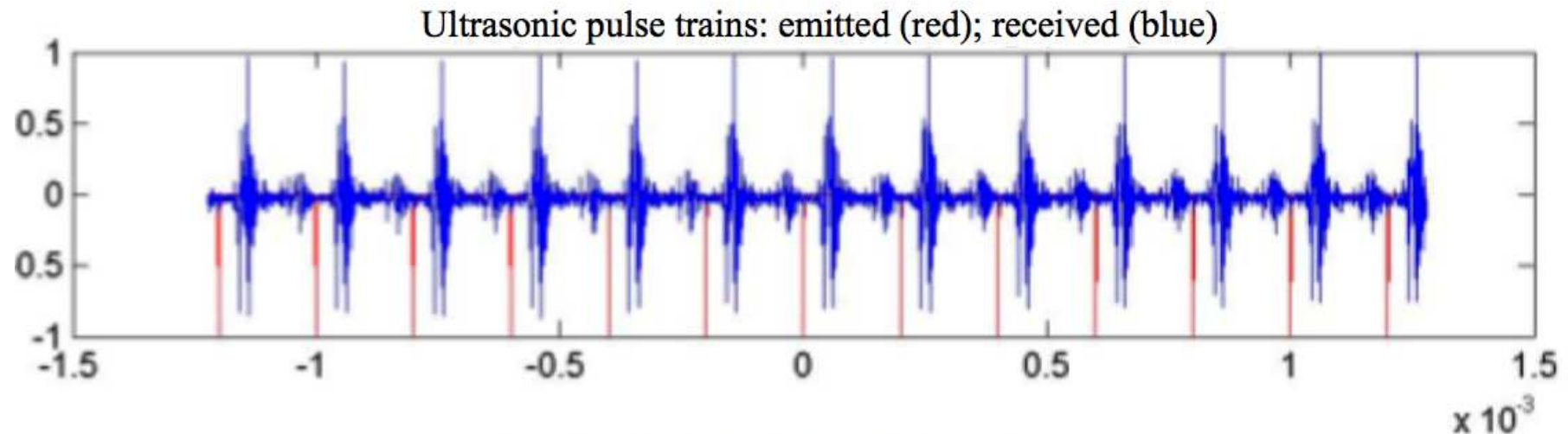
- New estimation procedure – reduce the error propagation effect (WarpCom)

$$t \xrightarrow{\mathbf{U}} t_w^{(K)} = \left( \frac{t}{\hat{a}_K} \right)^{1/K}$$



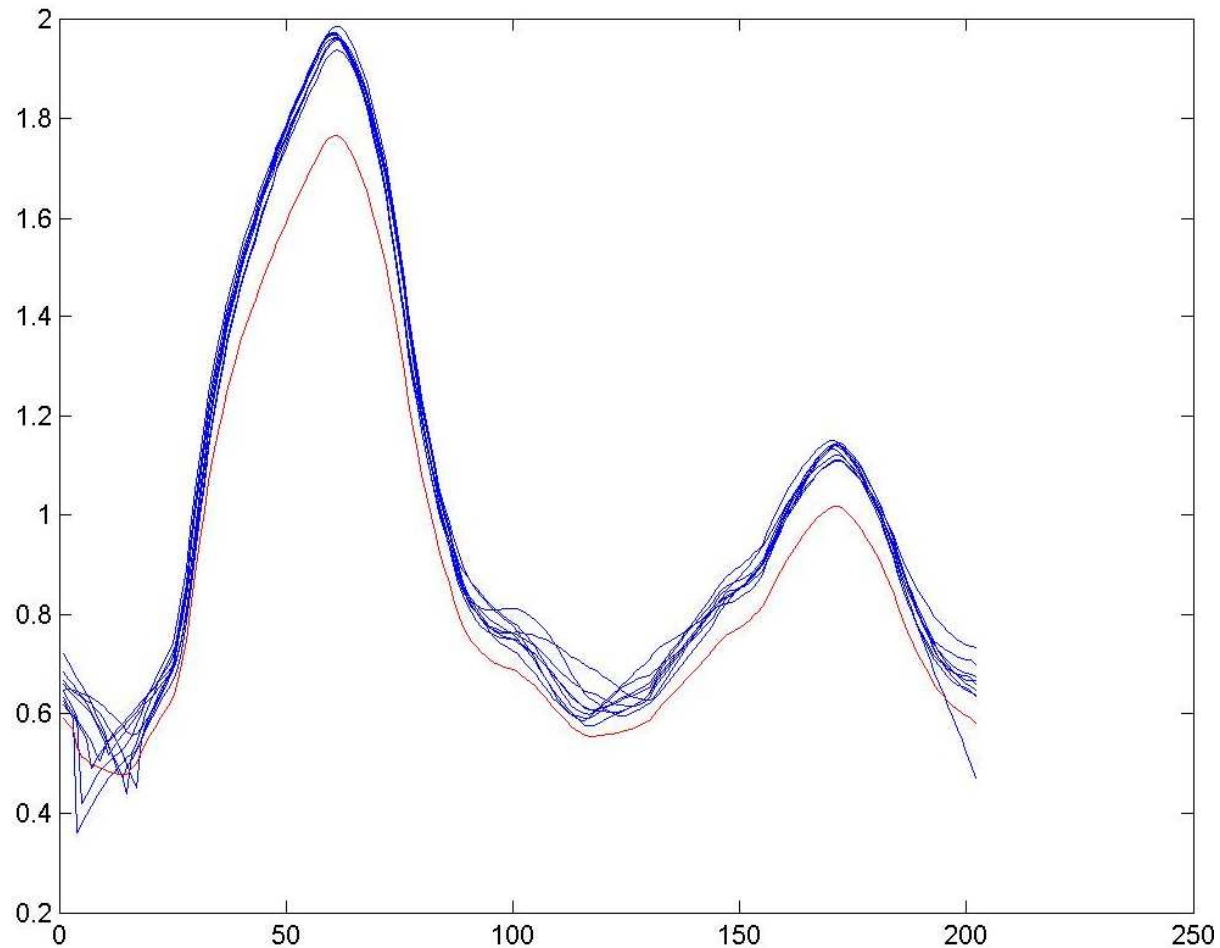


# Signal Processing Framework



# Signal Processing Framework

- **Warping-based polynomial phase modeling**

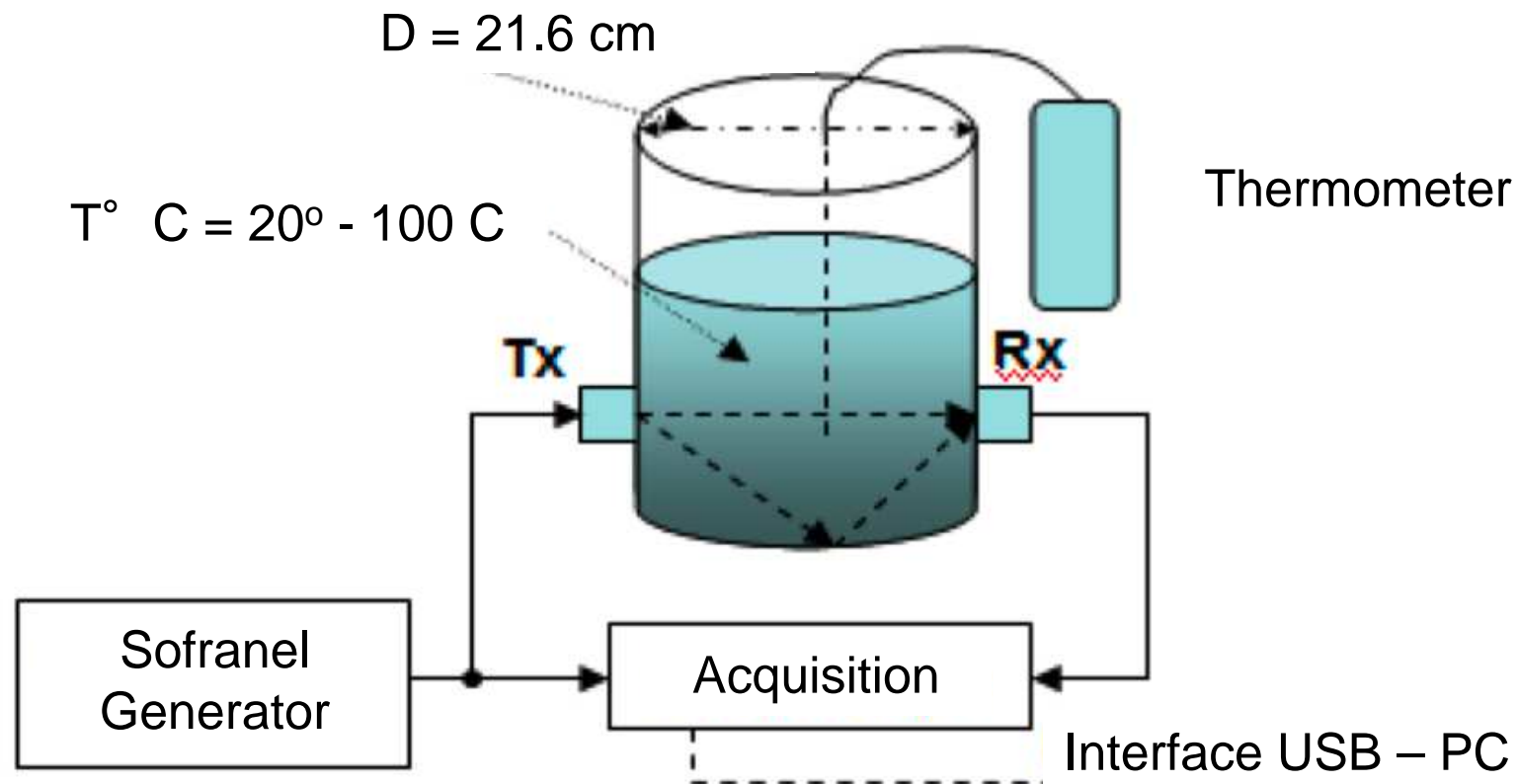


# Outline

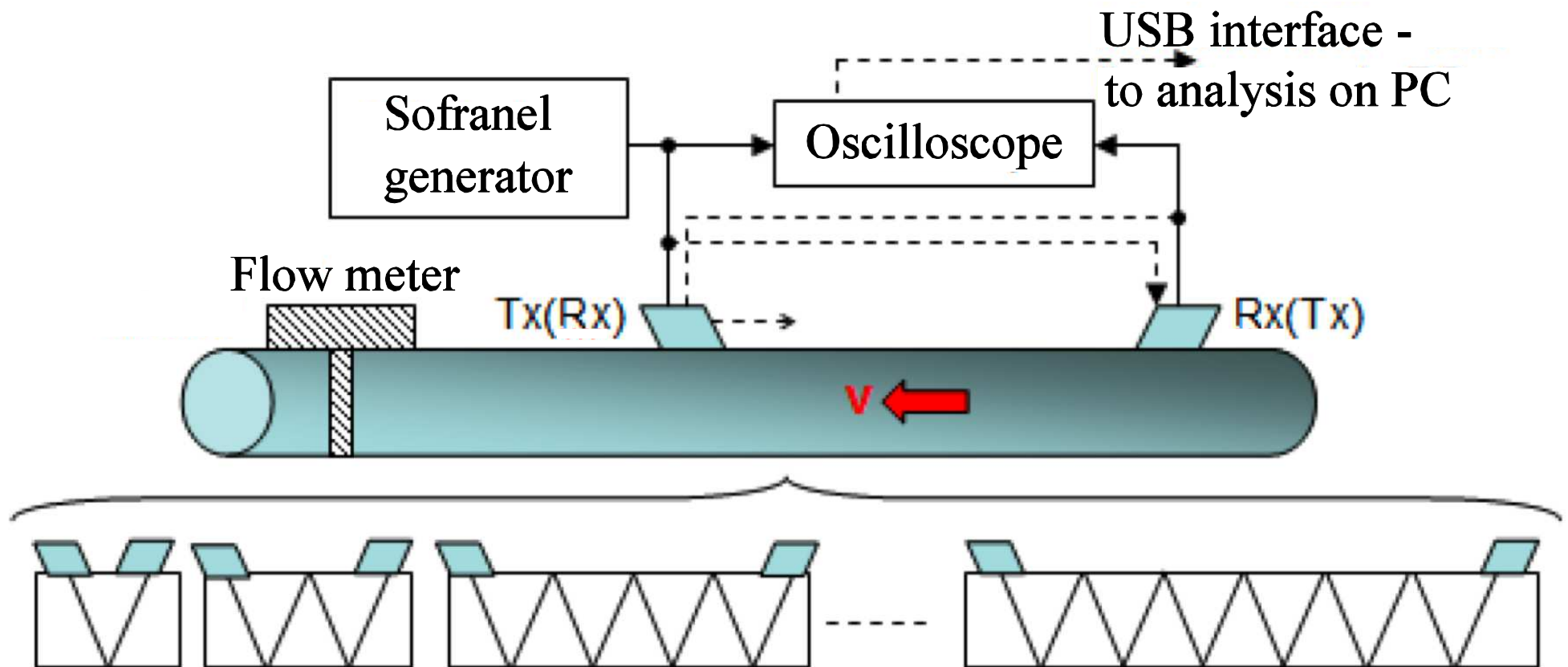
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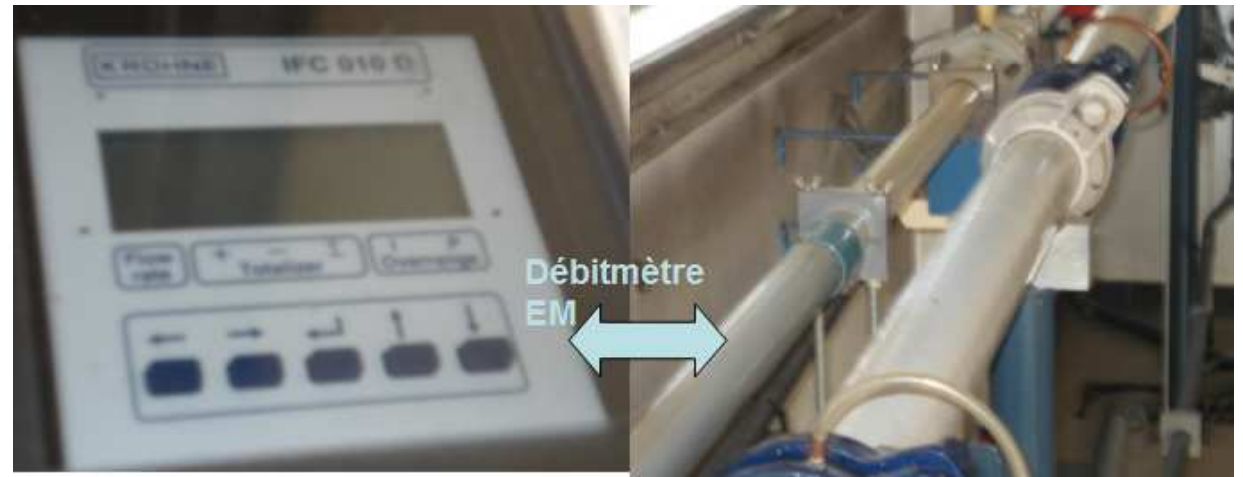
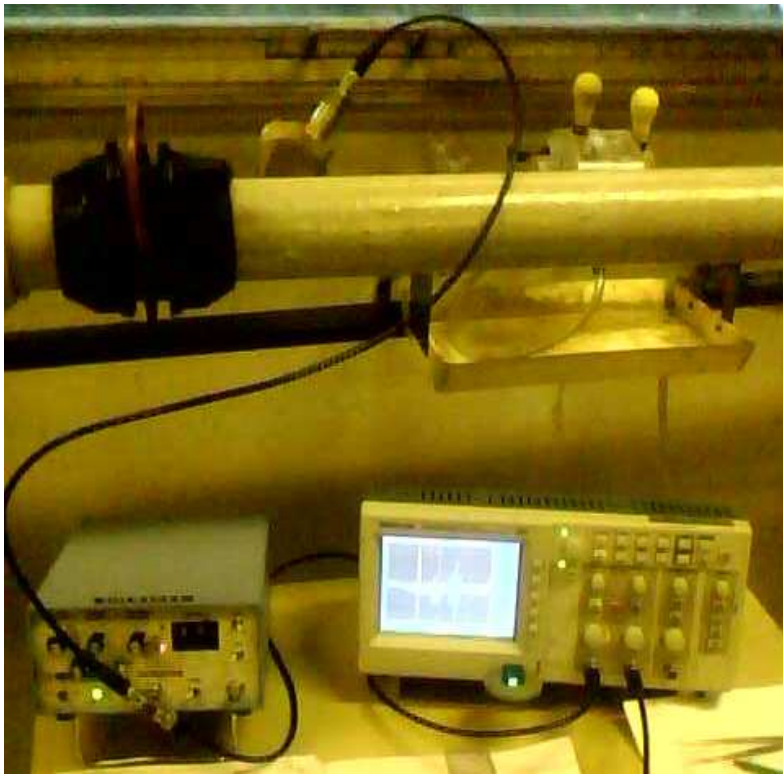
# Experimental setup for measuring temperature



# Experimental setup for measuring flow rate



# Experimental setup for measuring flow rate

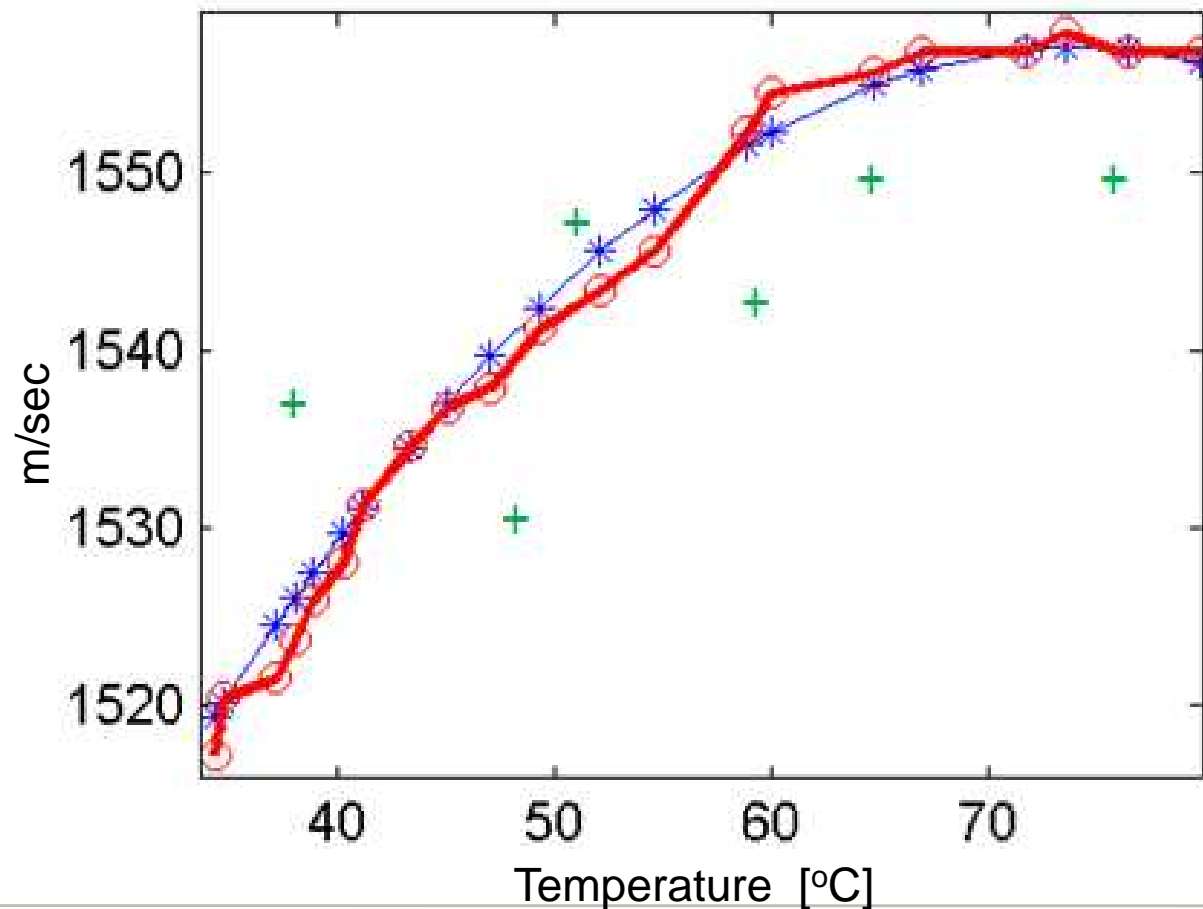




# Results: Temperature

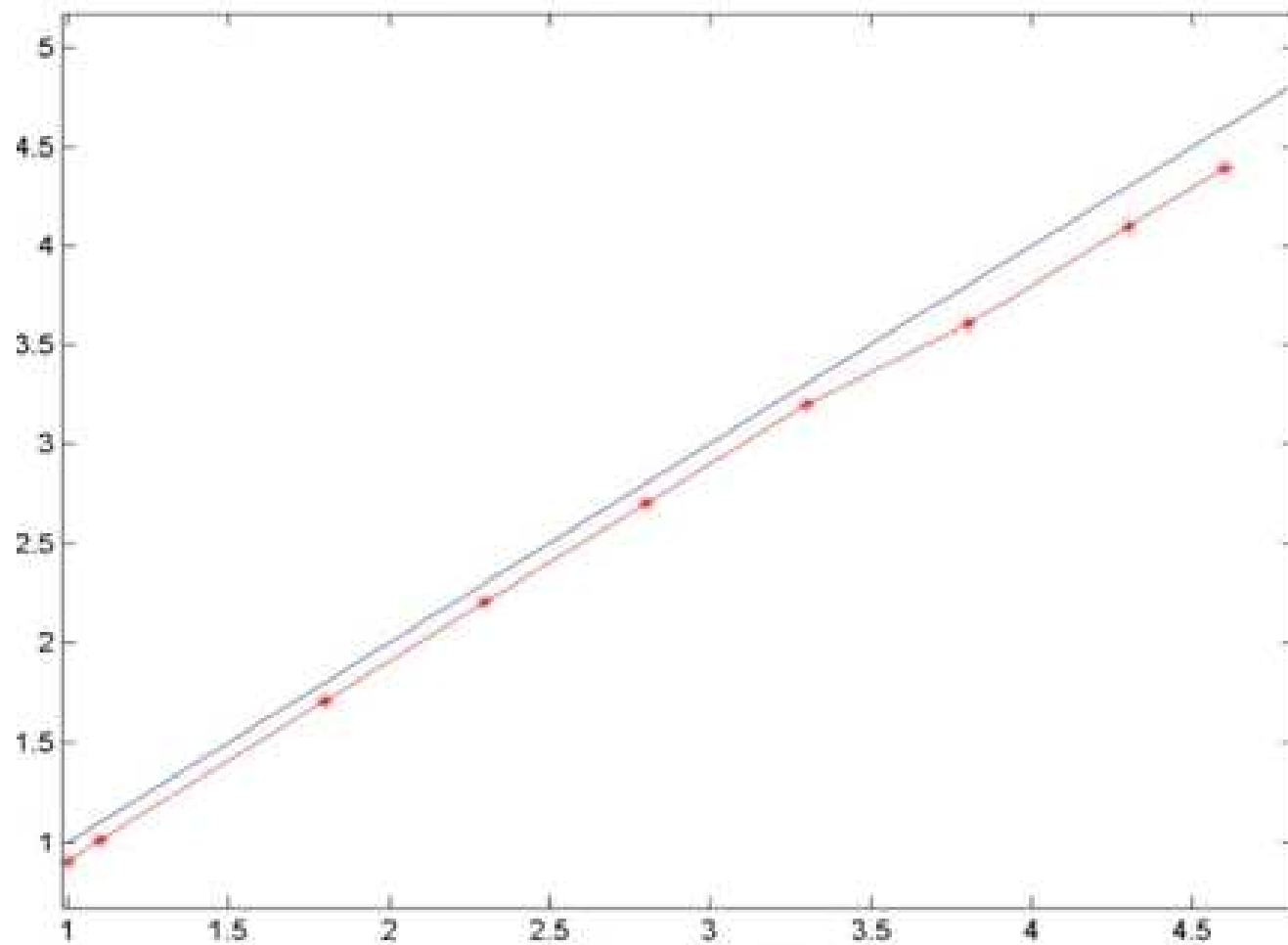
## Ultrasound velocity :

Theoretical (\*), Estimated by Enveloppe Detector (+), Estimated by Phase Modeling (o)



# Results: Flow rate

Théoretical vs Estimated flow rate



# Conclusion

Physics of ultrasound propagation + non-stationary signal processing =>

good estimation of the time of arrival =>

good estimation of the hydraulic parameters (temperature, flow rate)

## FUTURE WORKS

Wide – bande signals and Matching Filtering

*But need to model accurately the effects of the propagation...*

***NEED FOR MORE ADVANCED SIGNAL PROCESING !***