

Generate images from sound

Hervé Liebgott

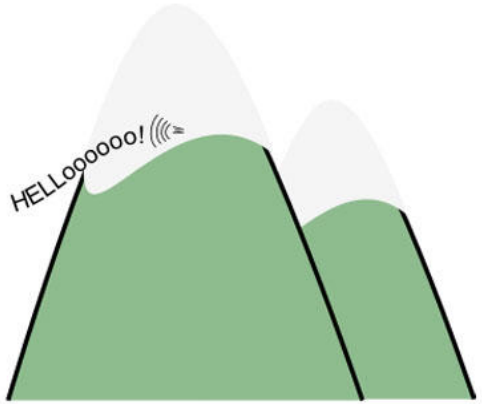
Prof. University of Lyon

CREATIS

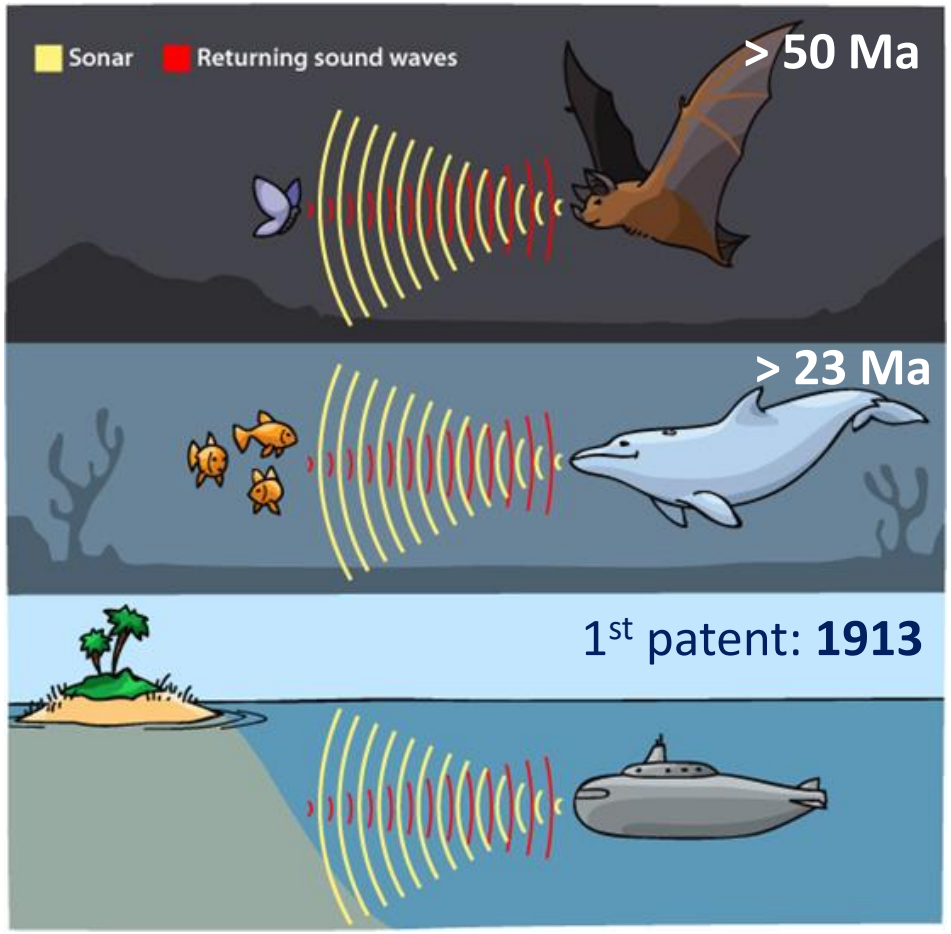
22/04/2019

Physical principle of echography



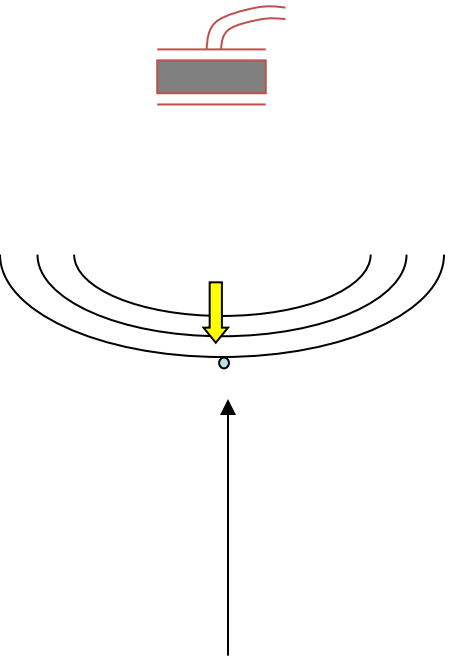


Sens the environment with sound waves: a natural phenomenon

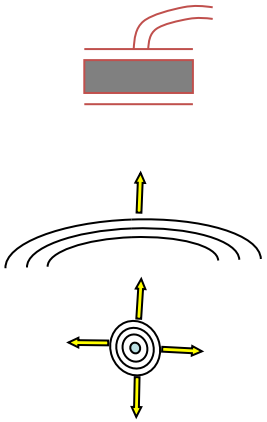


- **Medical ultrasound imaging**
  - 1st use in 1956 in Glasgow
  - becomes popular in the 70s

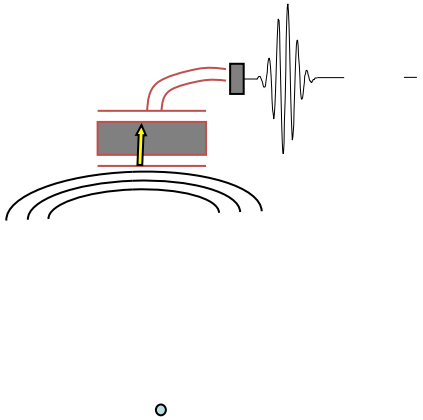
Physical principle of echography



One scatterer



One echoe is generated

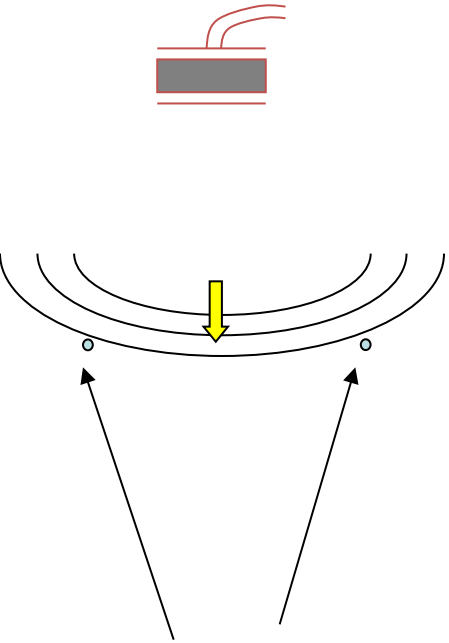


One signal is generated

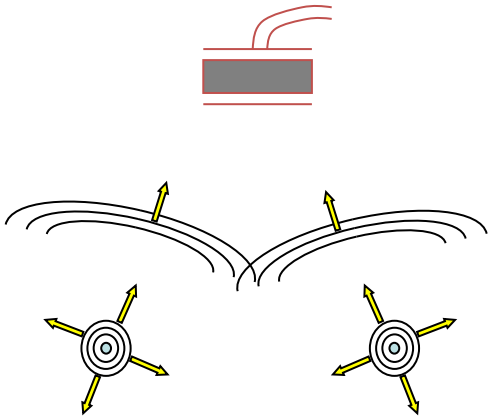
Arrival **time** is linked to **distance** of the scatterrer

Amplitude is linked to the **echogenecity** of the scatterer

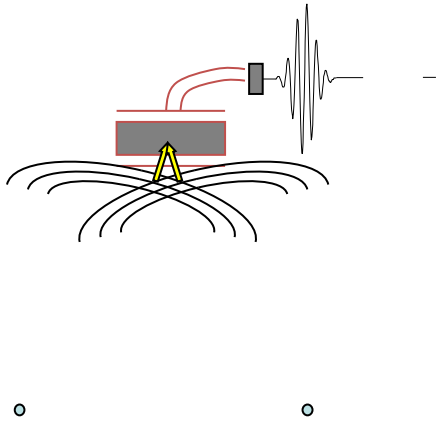
Physical principle of echography



Two scatterers



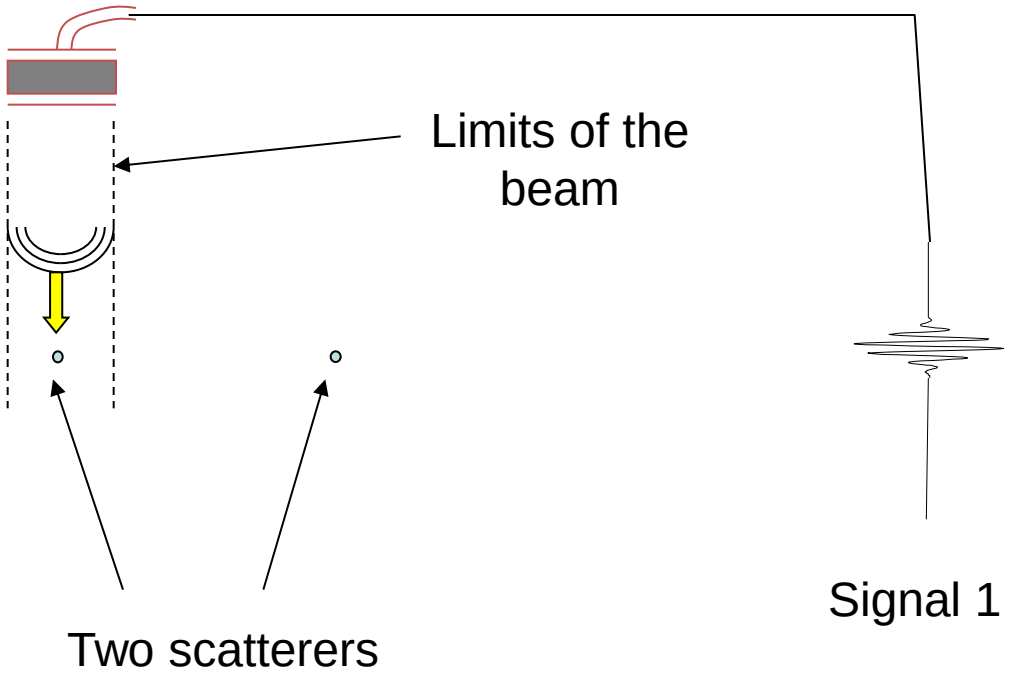
Echoes are generated at the same time (same diustance from transducer)



Only one signal is generated ➔ ambiguity

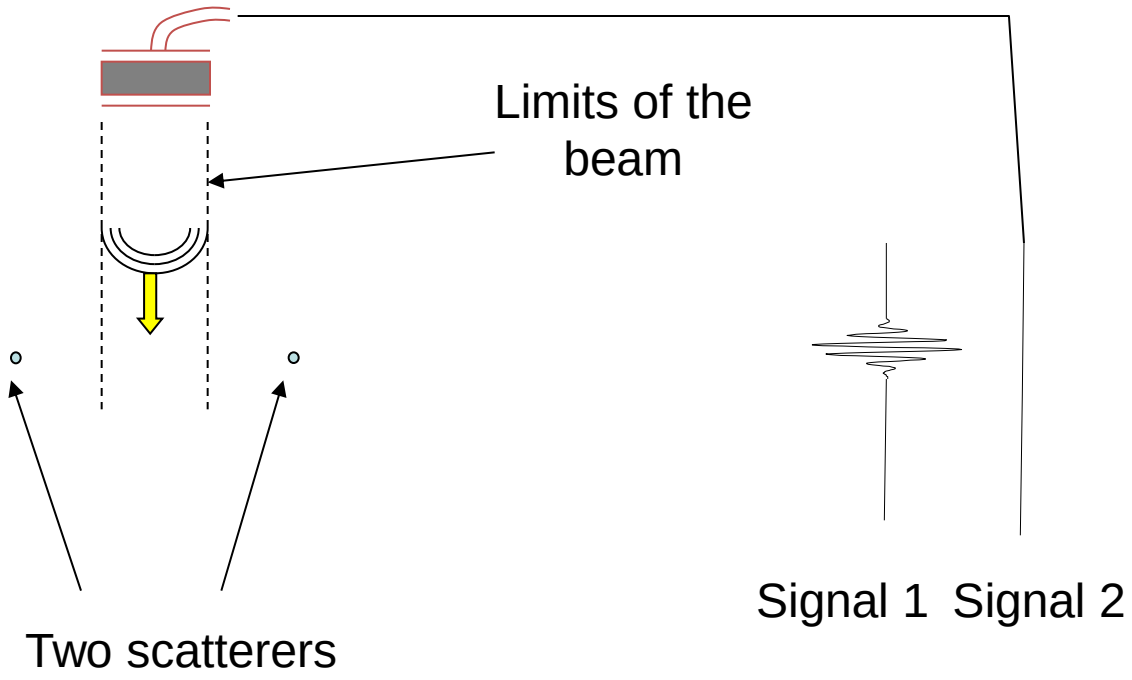
Physical principle of echography

Solution: limit the insonified region and sweep the ROI



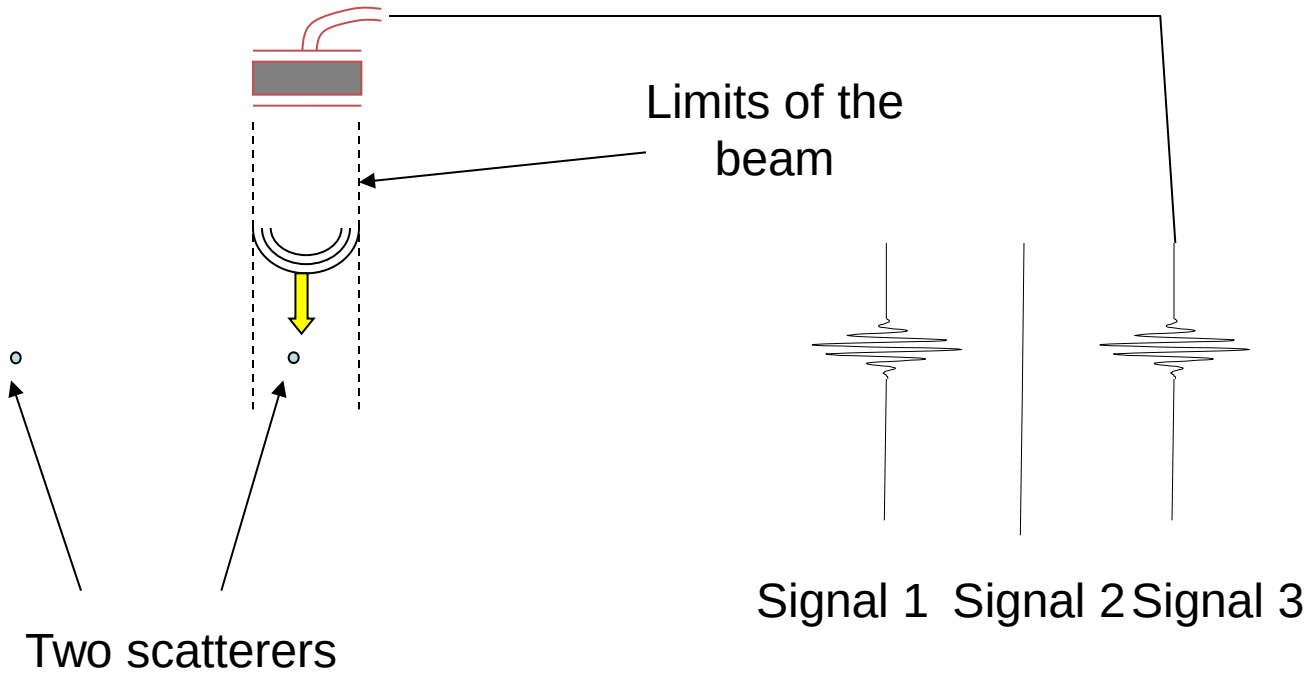
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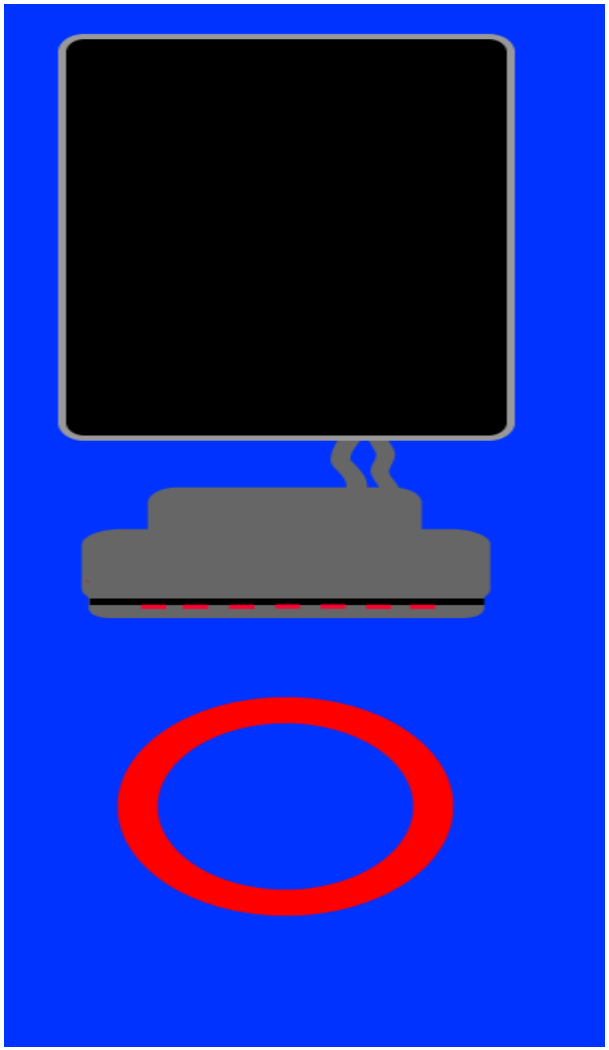


Physical principle of echography

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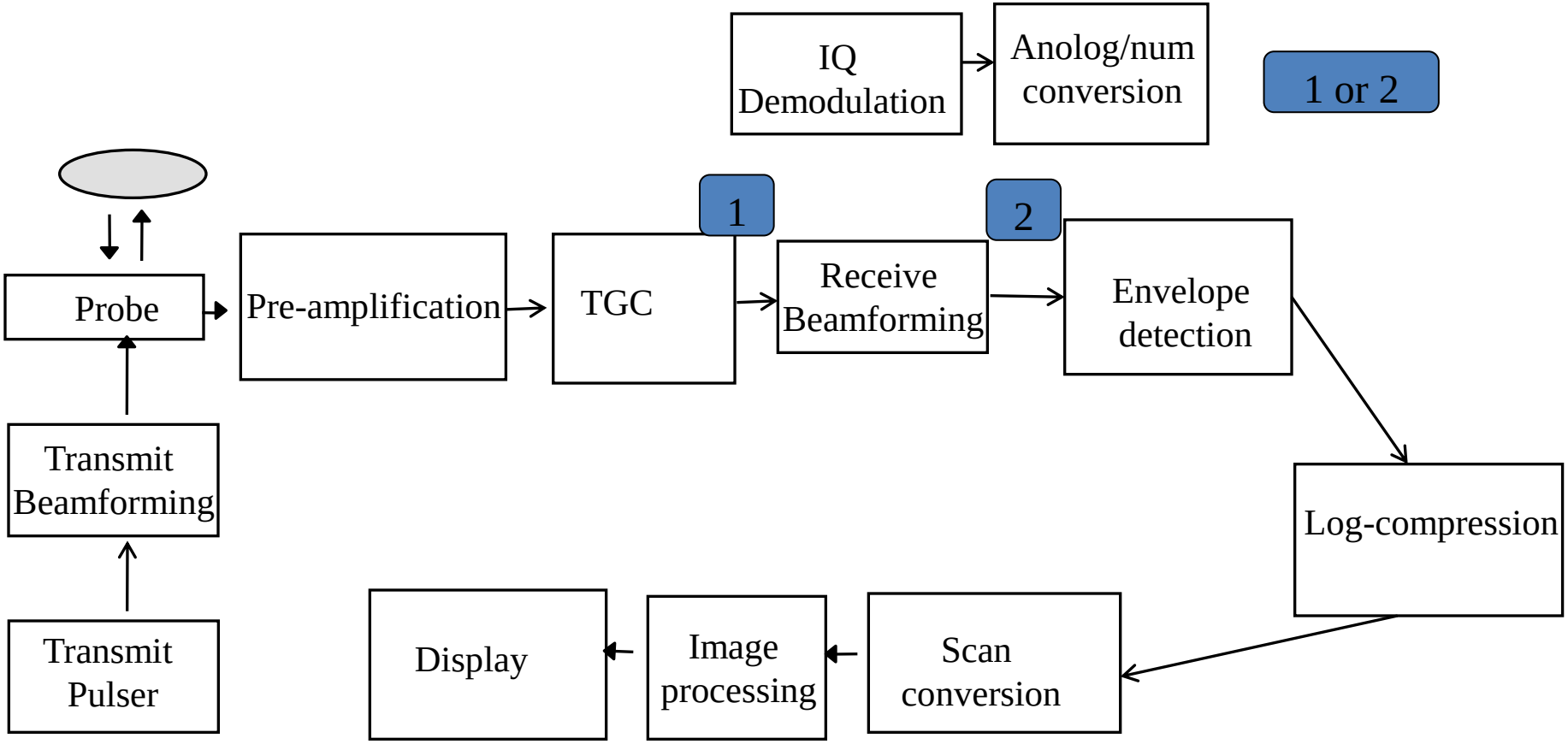


An image can be constructed columm after column
(we speak about RF lines or A lines)



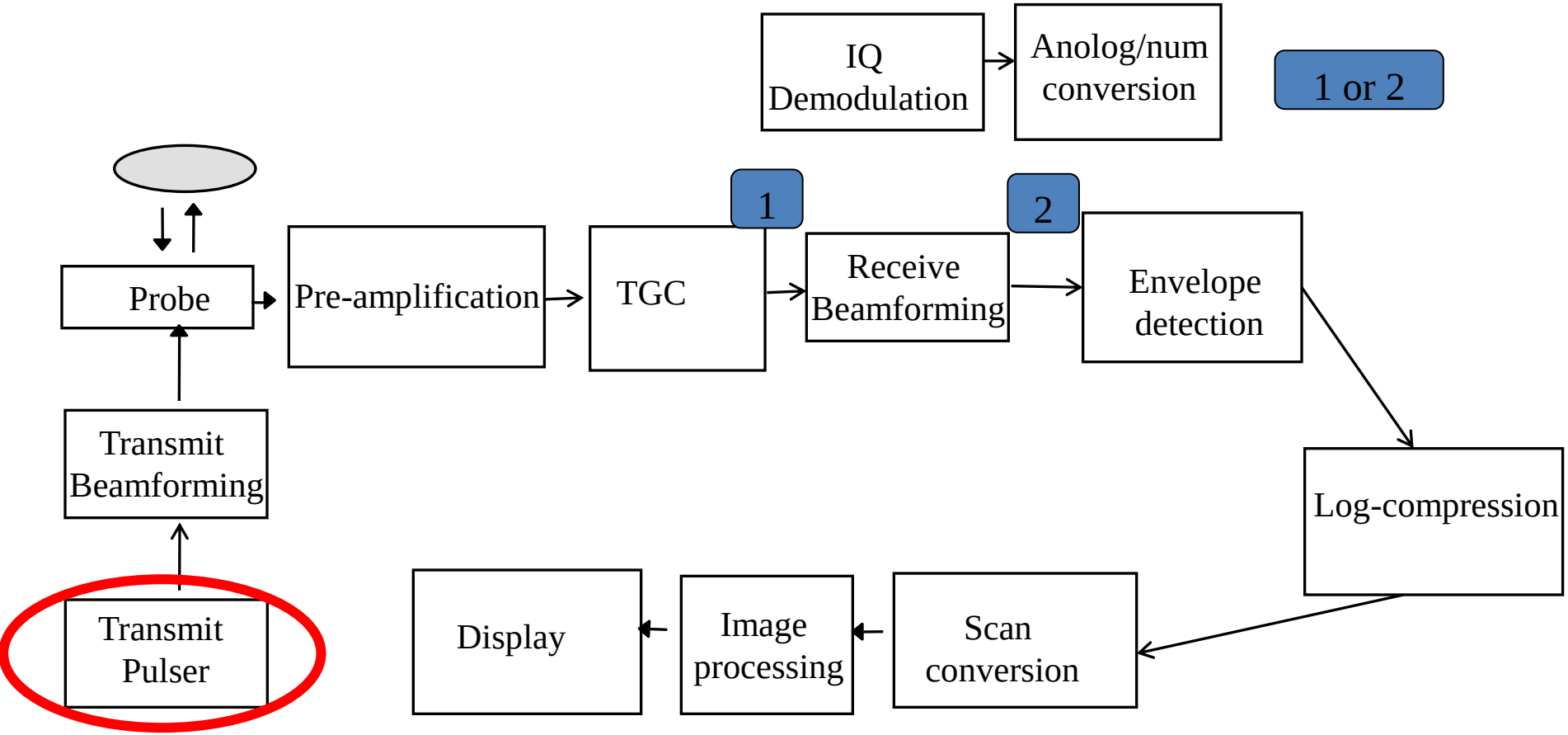
www.howequipmentworks.com

All steps to construct an image: inside the ultrasound system



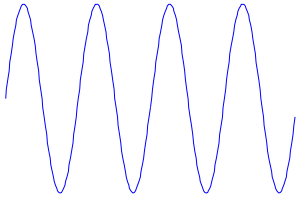
Probably each step can influence the quality of the estimated motion field

All steps to construct an image: inside the ultrasound system



Excitation signal

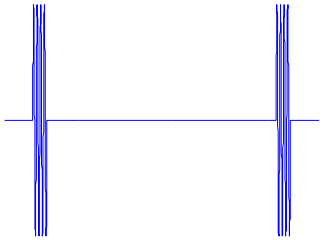
- Monochromatic sinusoïdal excitation
  - fixes the transmit frequency
  - no imaging but used in **continuous wave Doppler**



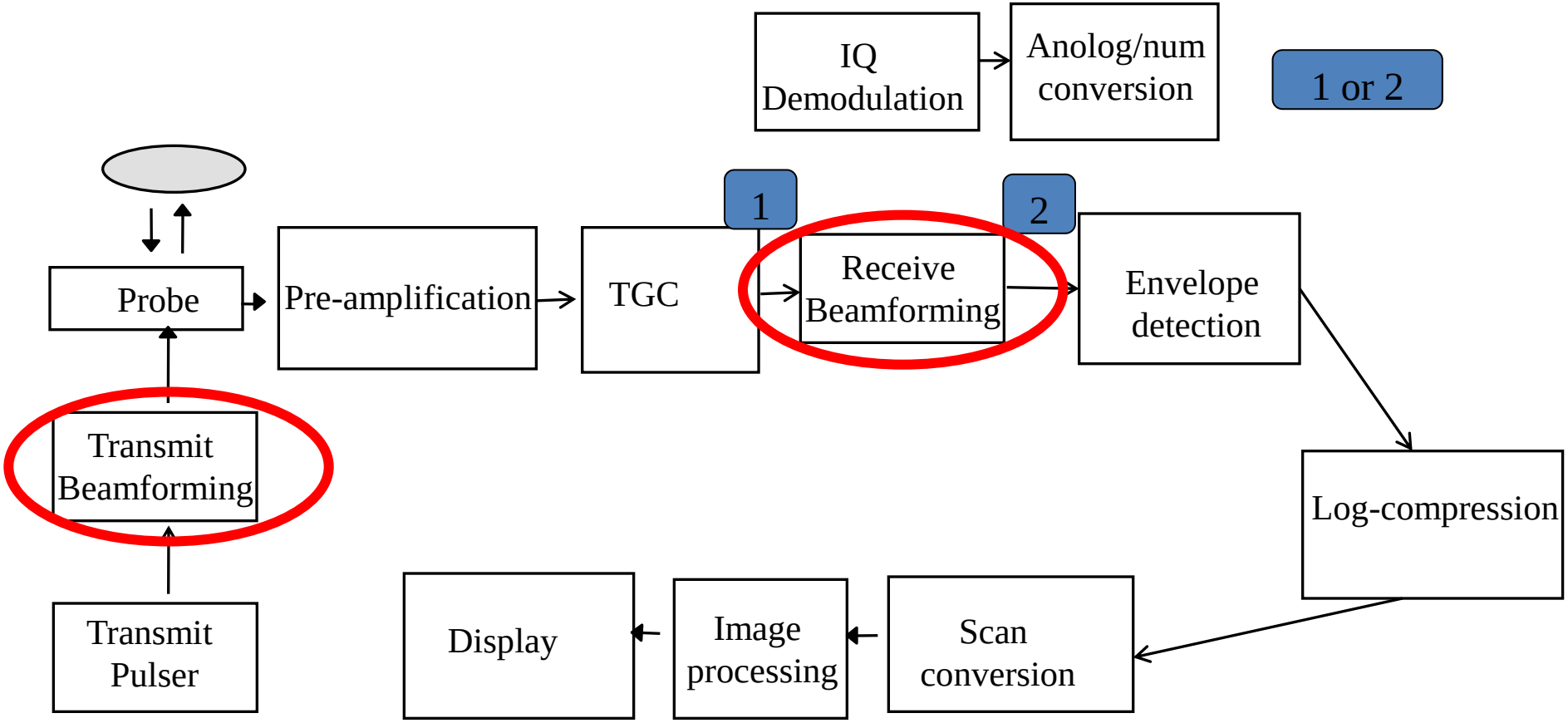
- Short pulse (close to a delta function)
  - around100 V and length 100 ns
  - exploits the full bandwidth
  - best possible resolution
  - probably the kind of pulse used when you want to **track speckles**



- Short sinusoïdal pulse
  - compromise
  - fixes the central frequency and permits imaging
  - used in **color Doppler**



All steps to construct an image: inside the ultrasound system



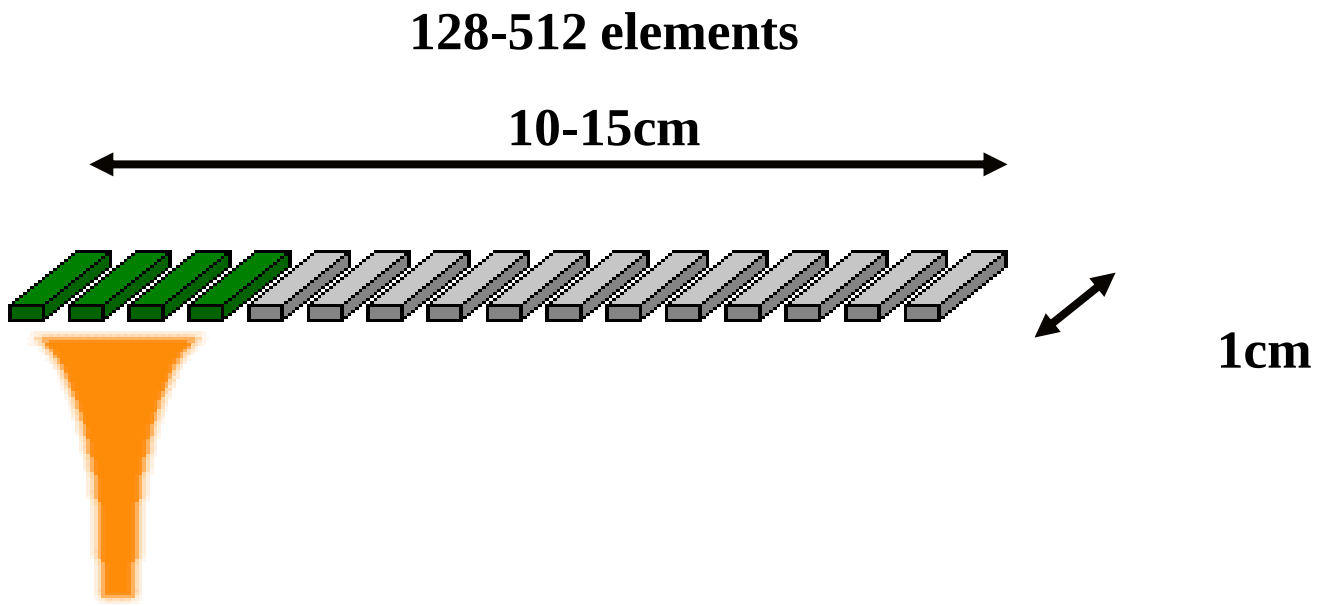
Imaging is performed with an array of elements

In order to obtain a beam with «better» characteristics than with a unique transduder several elements are used together

Through delays and apodization arrays permit

steering and sweeping the beam
shaping the beam

1D arrays



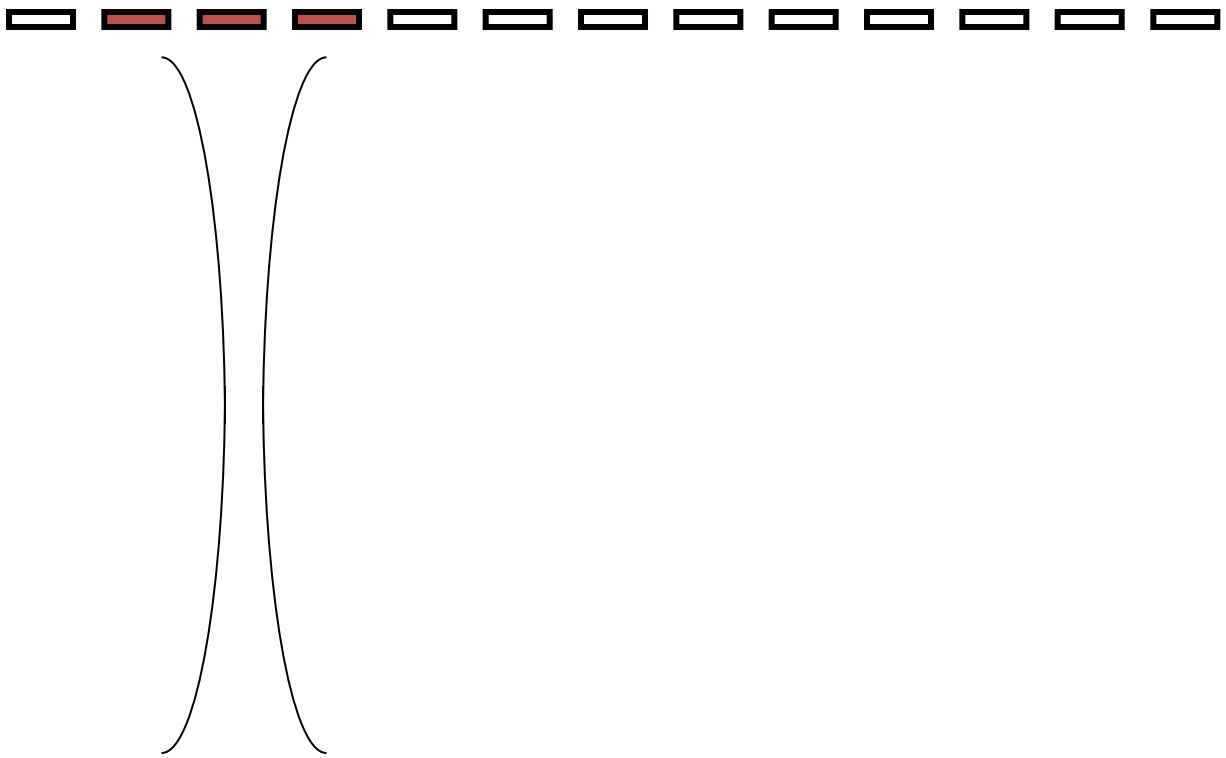
Elements are used together in subgroups

- such super-elements transmit thinner beams
- the beam can be swept electronically

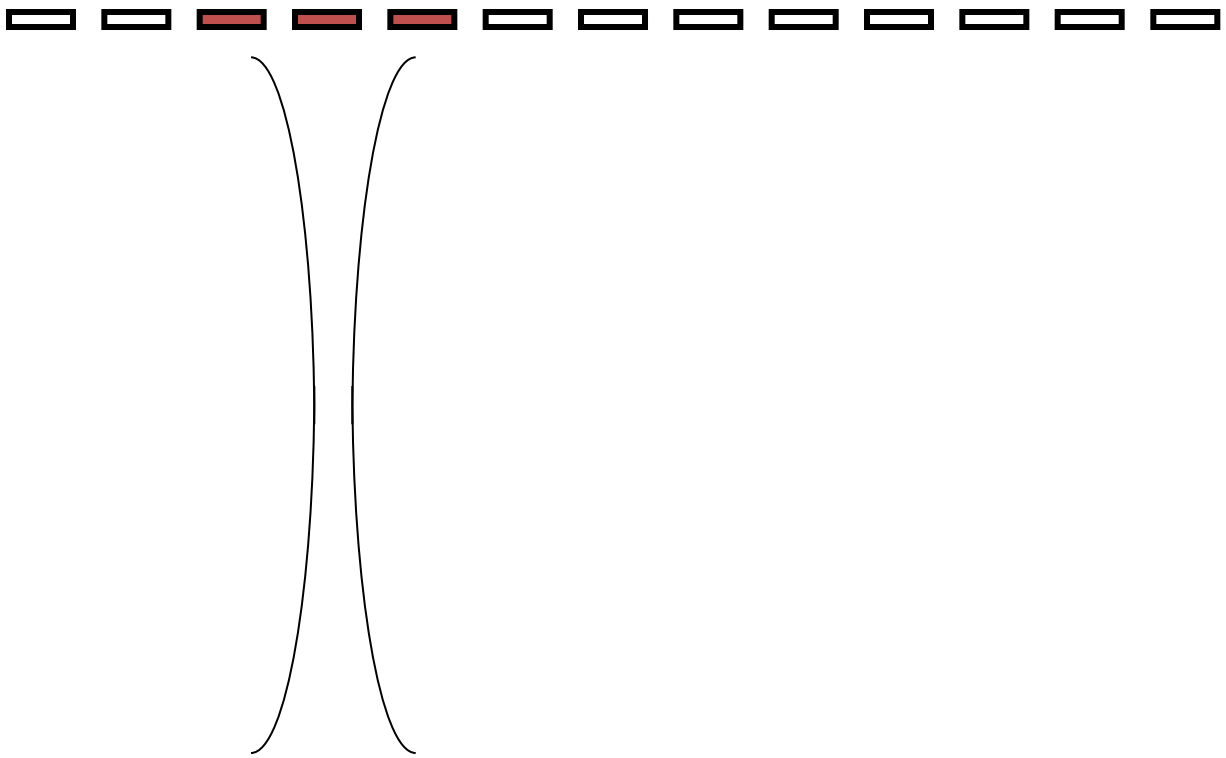
Linear scan



Linear scan



Linear scan



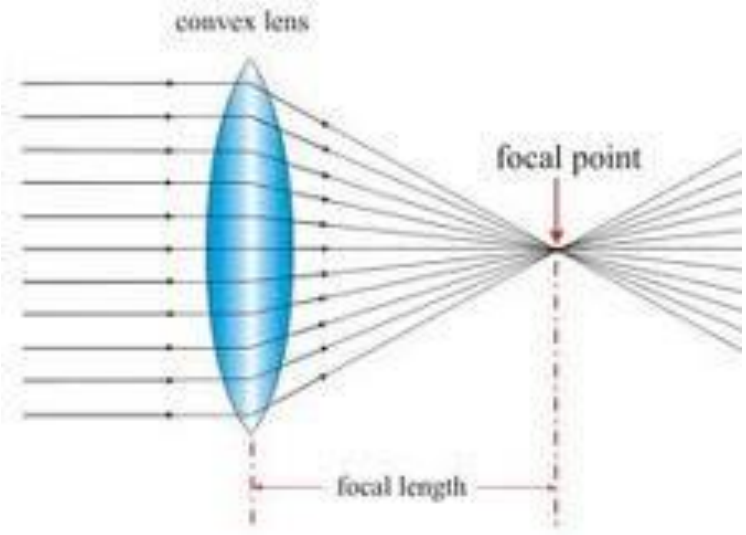
Linear scan

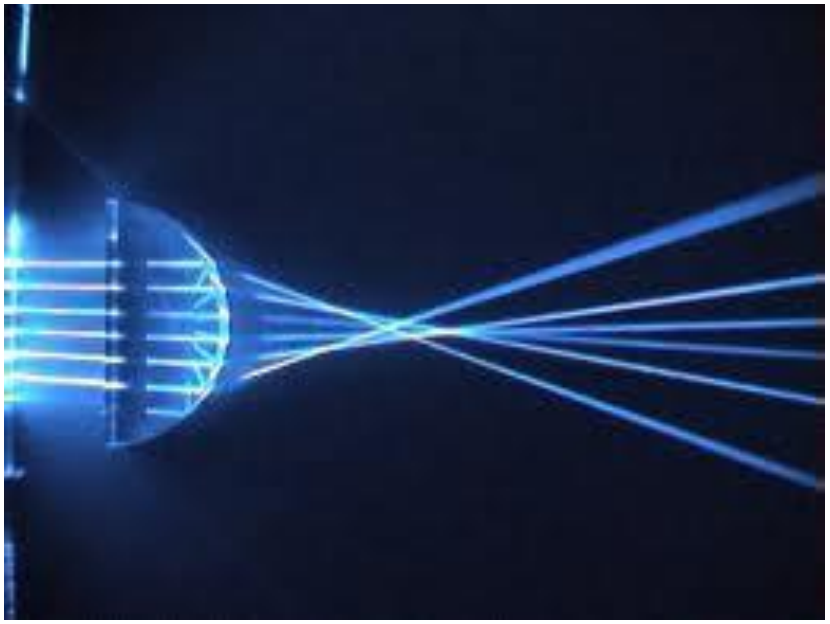


Focusing

The ultrasound wave naturally diverges.
Focusing is needed to “concentrate” the beam

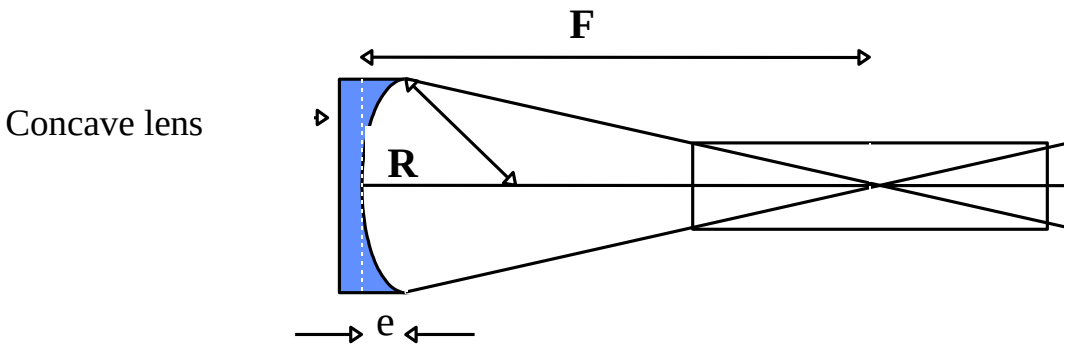
Focusing = compensate for the ≠ times of flight





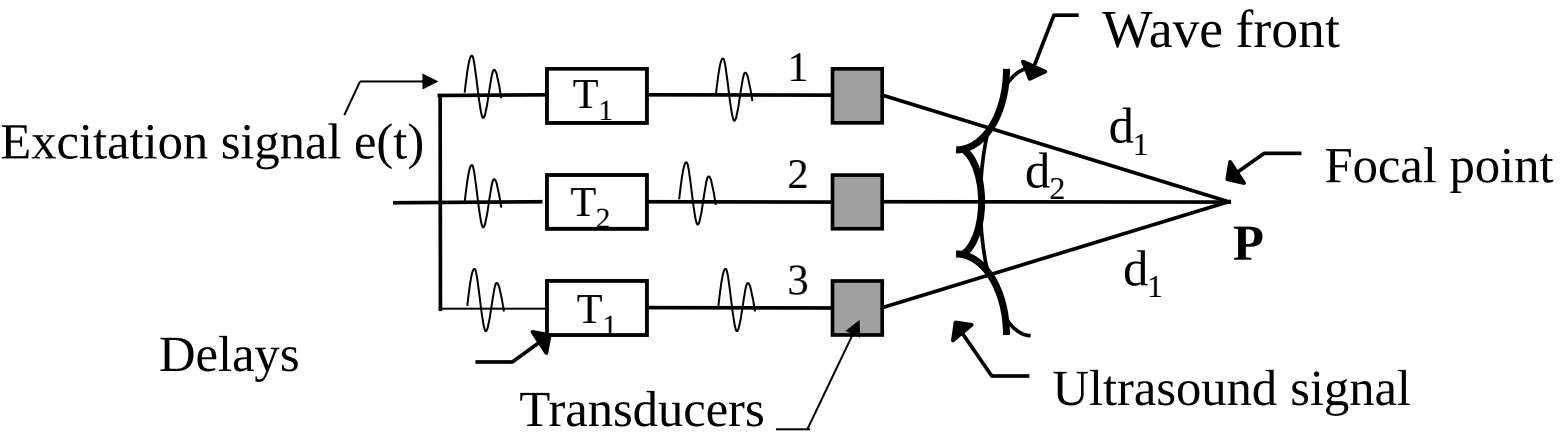
F number = ratio focal length / lens diameter

Mechanical focusing with a physical lens

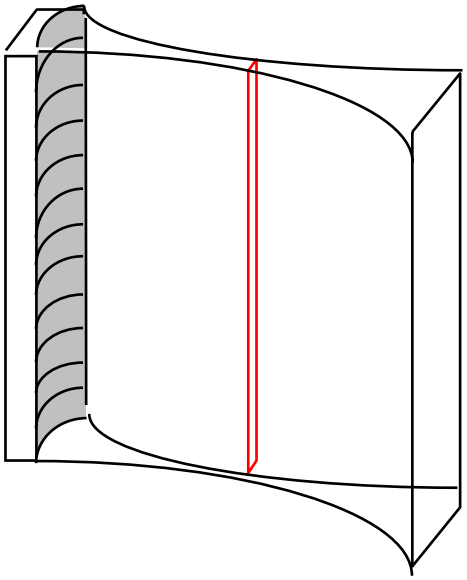


Electronic focusing

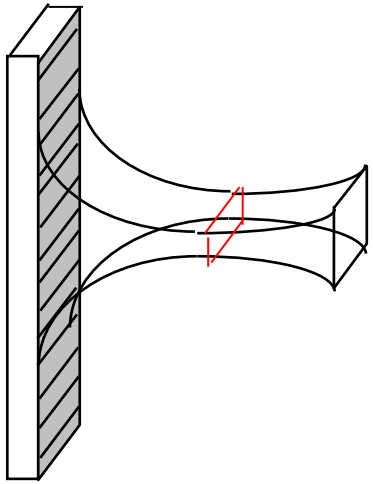
- elements are excited at different times in transmit
- different delays are used when receive beamforming is considered



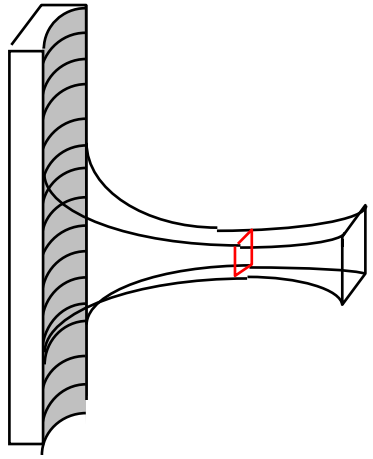
Typically both mechanical and electronic focusing are used together



Mechanical focusing
In the out of plane direction



Electronic focusing



Combination of both

The true transmit or receive beam profile

Transmitting with an array or sensing with it is a **sampling problem**

Strong similarities with Fourier analysis

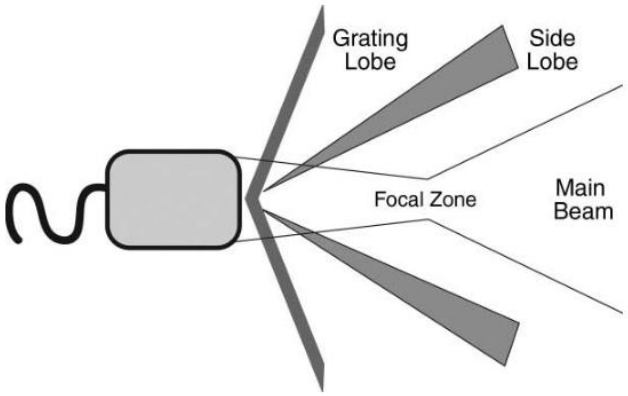
Ideally we want to transmit or receive in a single direction BUT due to non infinite apertures and diffraction there are **side lobes** in the beam pattern.

Apodization can be used to reduce them (similar to using windows in Fourier)

Similarly to aliases in Fourier theory **grating lobes** appear if the sampling step (inter element spacing d) is too large

To « push » grating lobes beyond 90°

$\Rightarrow$ d< lambda/2



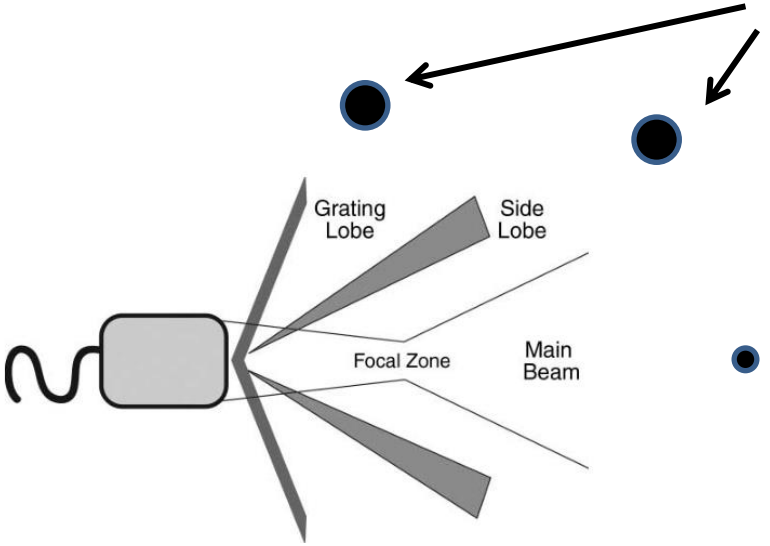
Feldeman 2009

The problem of side and grating lobes for motion imaging

Due to the secondary lobes we sense in the wrong direction

Even if secondary lobes are much weaker it can be a problem

Strong scatterers in the directions of secondary lobes with low velocity v1



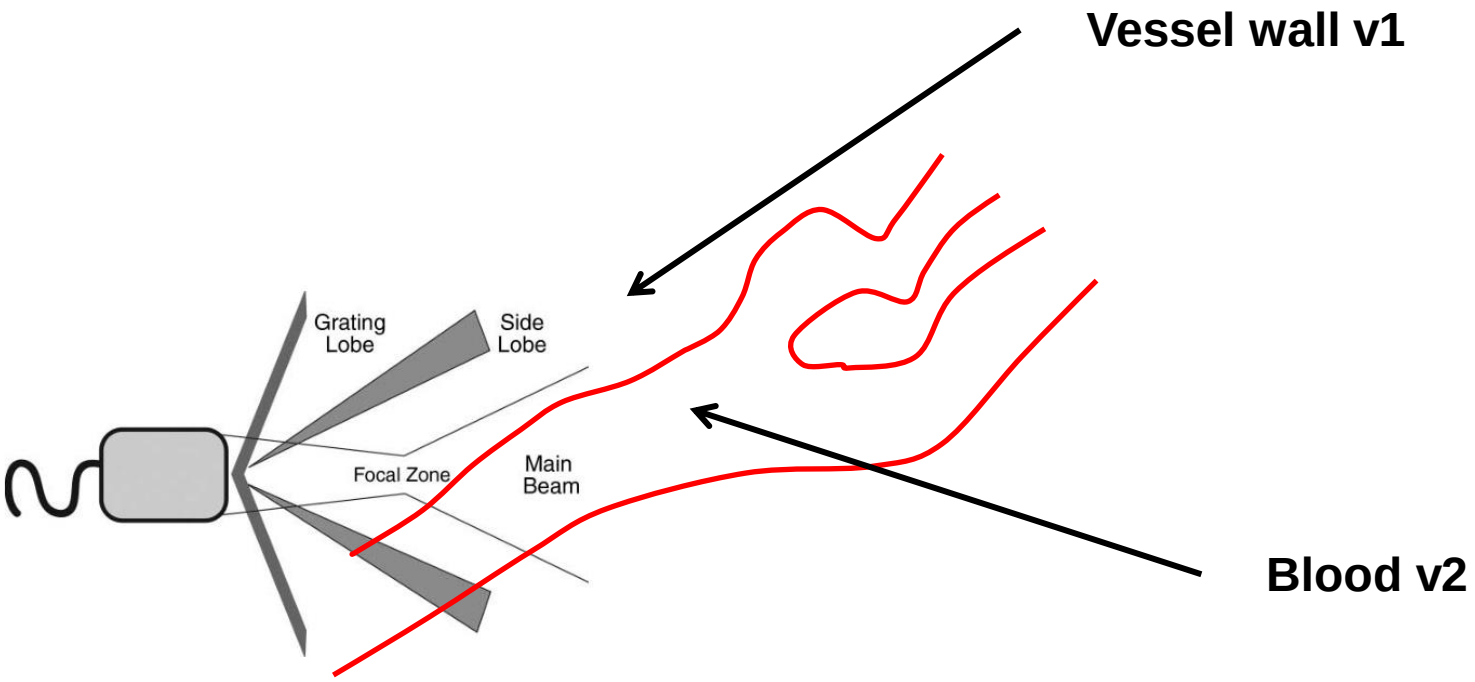
Weak scatterers in the directions of interest with high velocity v2

We want to measure v2 but the signal from v1 is higher

The problem of side and grating lobes for motion imaging

Due to the secondary lobes we sense in the wrong direction

Even if secondary lobes are much weaker it can be a problem



This can happen in **blood flow** imaging because **scattering from the blood is more than 40 dB weaker** than the surrounding tissue

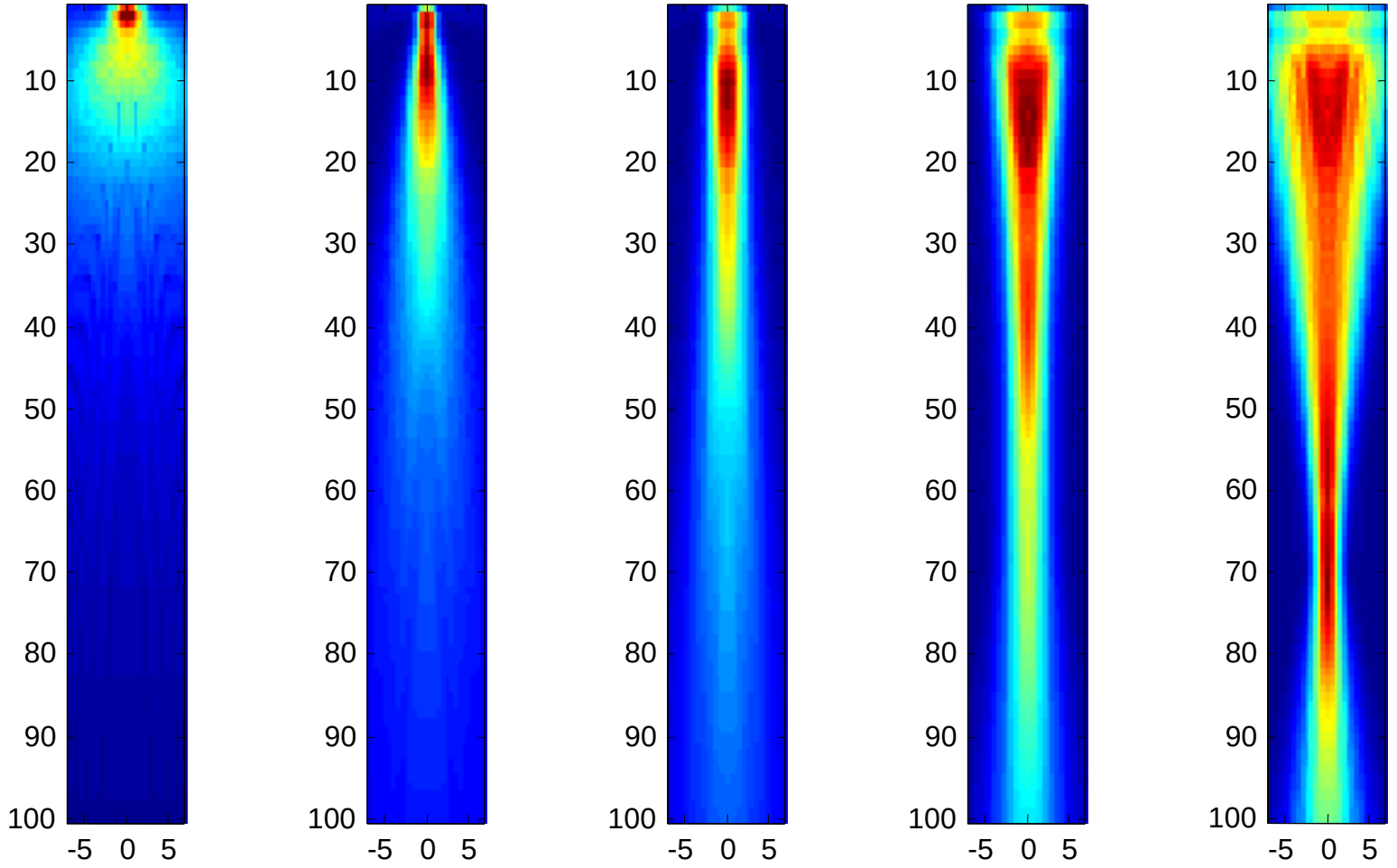
→ clutter filter

Influence of the different parameters on the shape of the beam: number of elements, focusing depth, apodization

Focusing at 70 mm

Apodization Hanning

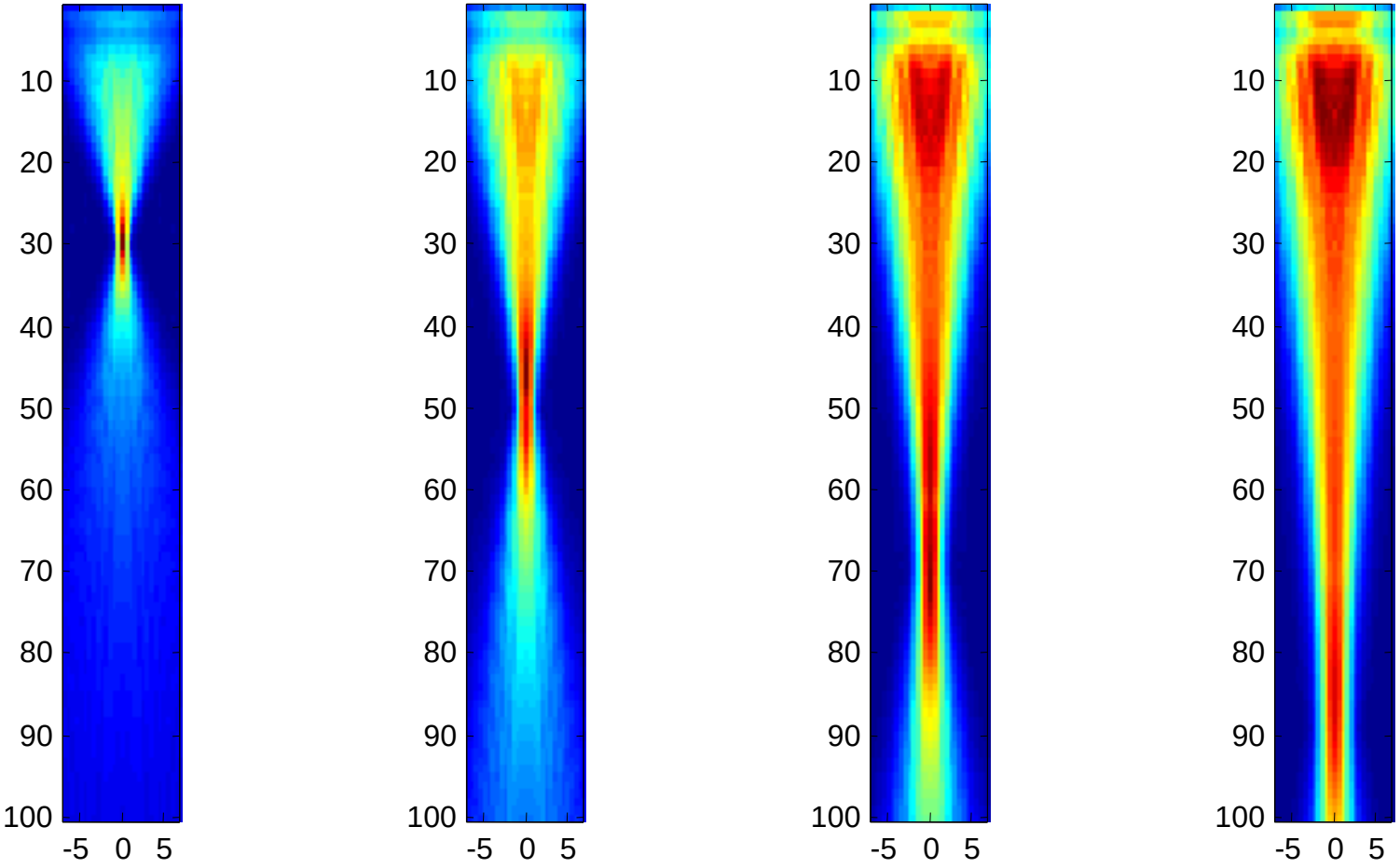
1-8-16-32 et 64 elements



Apodization Hanning

64 elements

Focusing at 30 50 70 and 90 mm



Hanning

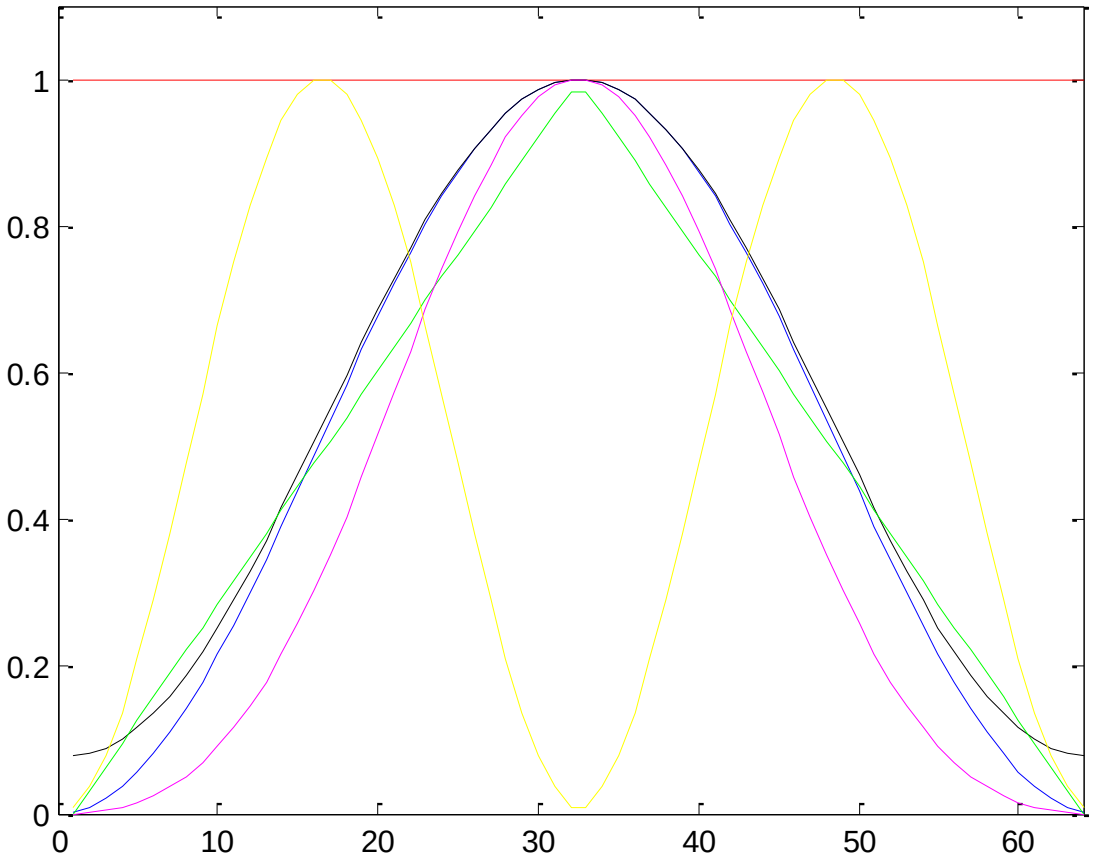
Boxcar, r

Hamming, k

Bartlett, g

Blackma, m

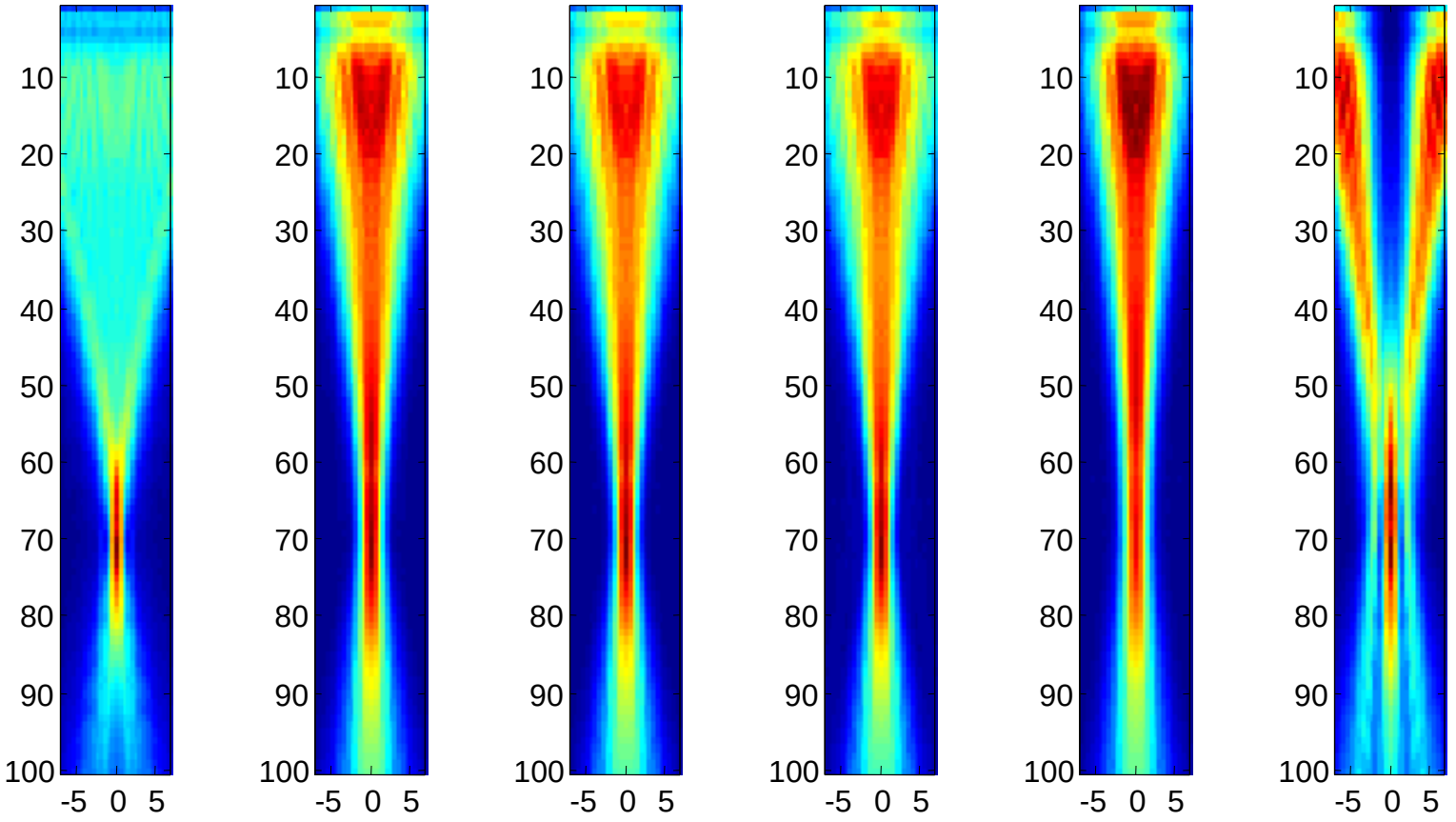
2 hanning y



64 éléments

Focusing at 70 mm

Apodization Boxcar Hanning, haming,bartlett, 2 hanning



Imaging single scatterers in such changing fields

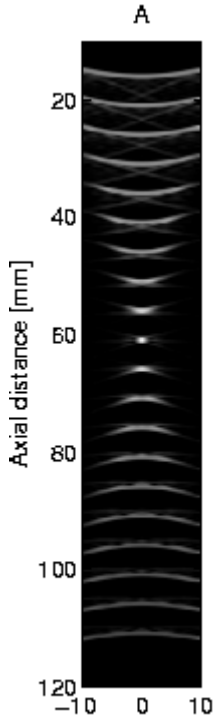
The image of one scatterer is called the point spread function (**PSF)**

It characterizes the system → resolution and contrast …

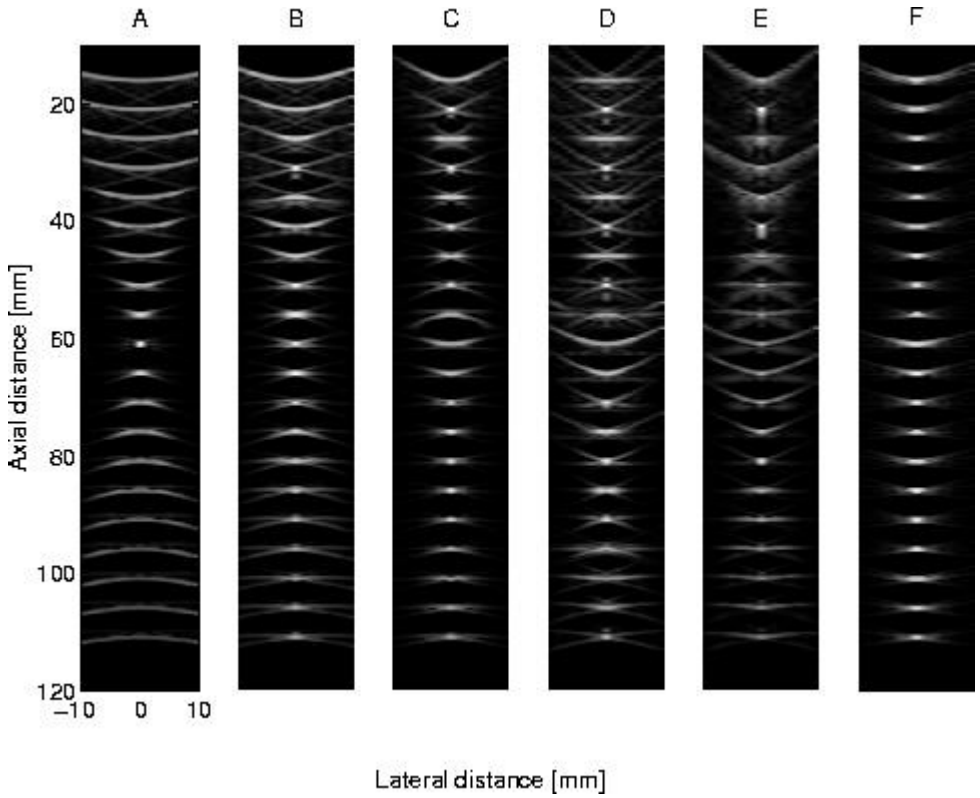
…and is linked to the beam shape

A different position of the scatterrer leads to a change in its shape or appearance

→ makes it (more) difficult to follow



Exploit beamforming to compensate for PSF spatial variations



Dynamic beamforming

multi-focusing in transmit (necessitates several transmissions)

continuous focusing in receive

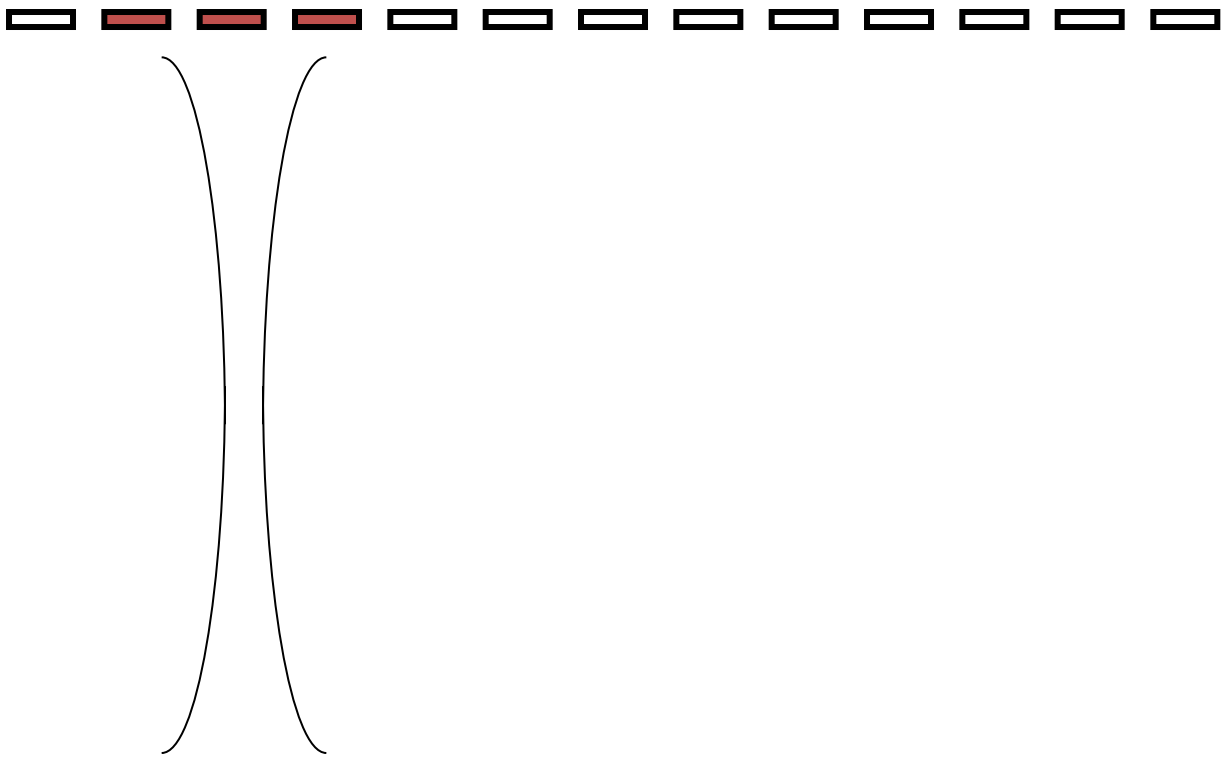
constant receive f-number (f#, *ie.* ratio focal depth / aperture size)

Let’s come back to sweeping

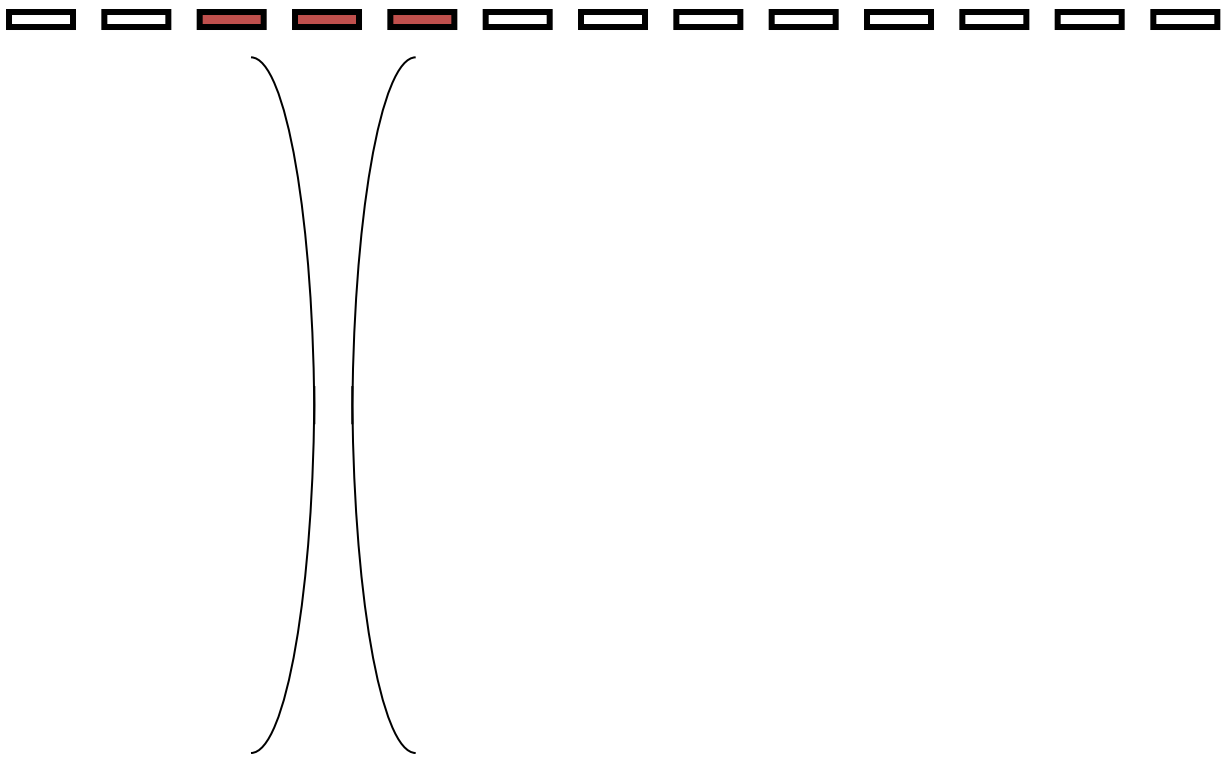
Linear scan



Linear scan



Linear scan

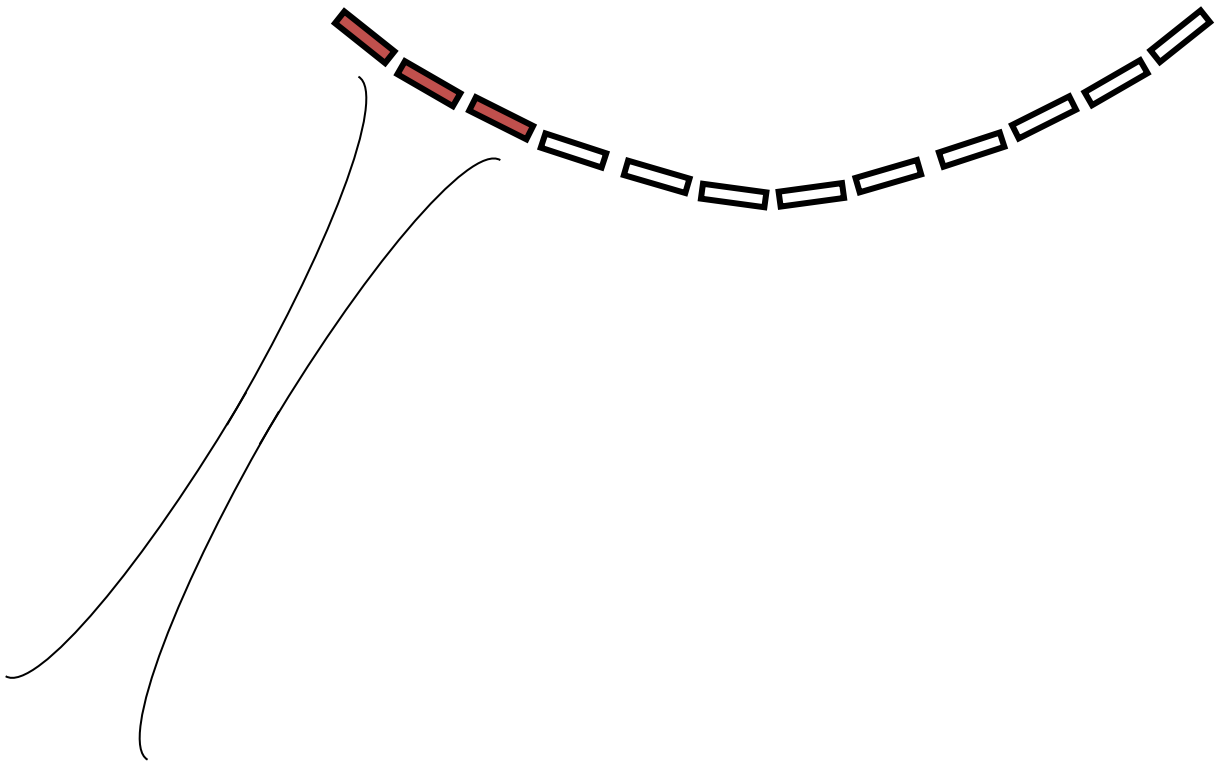


Linear scan

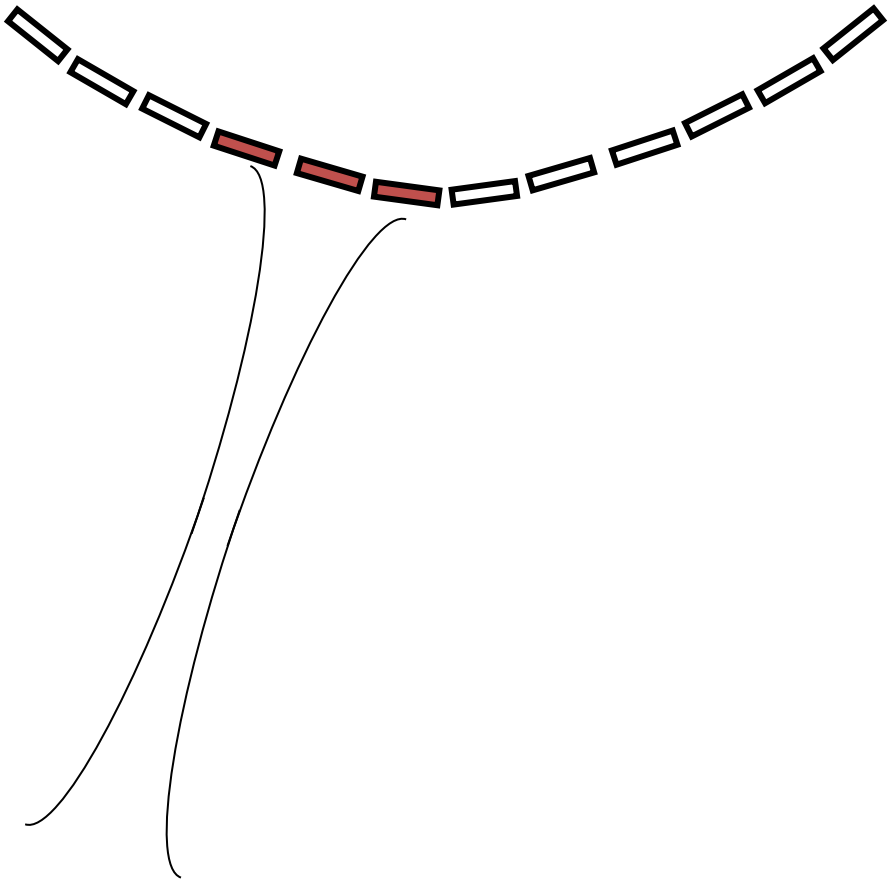


Moderate field of view but no « orientation »

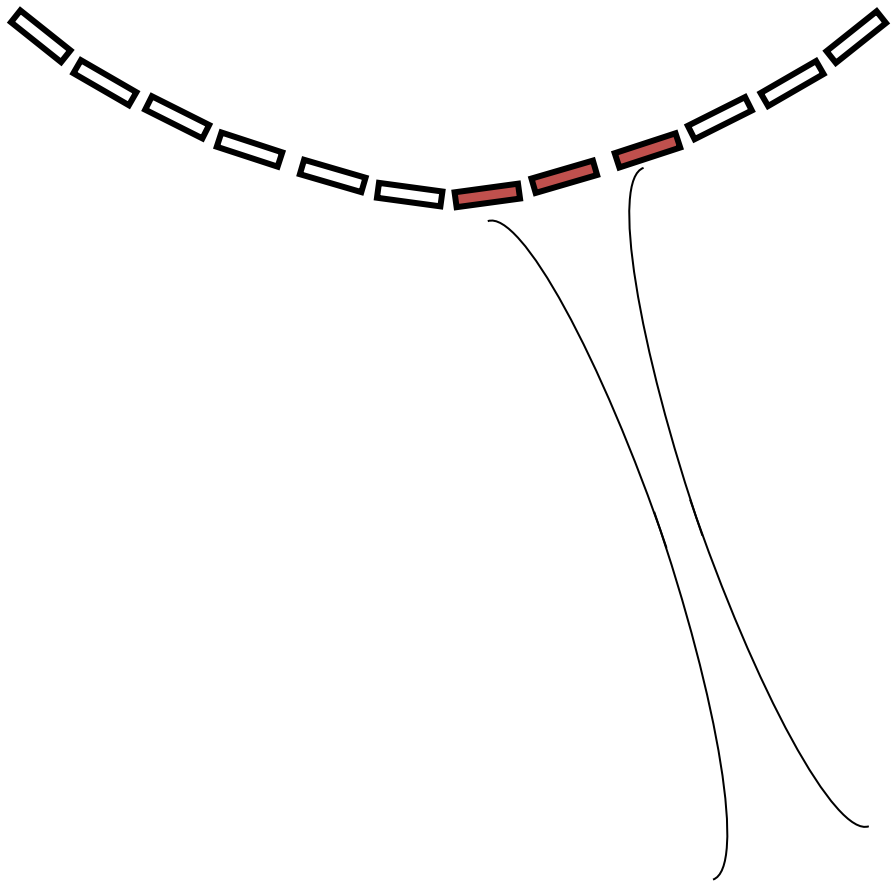
Sectorial scan: convex array



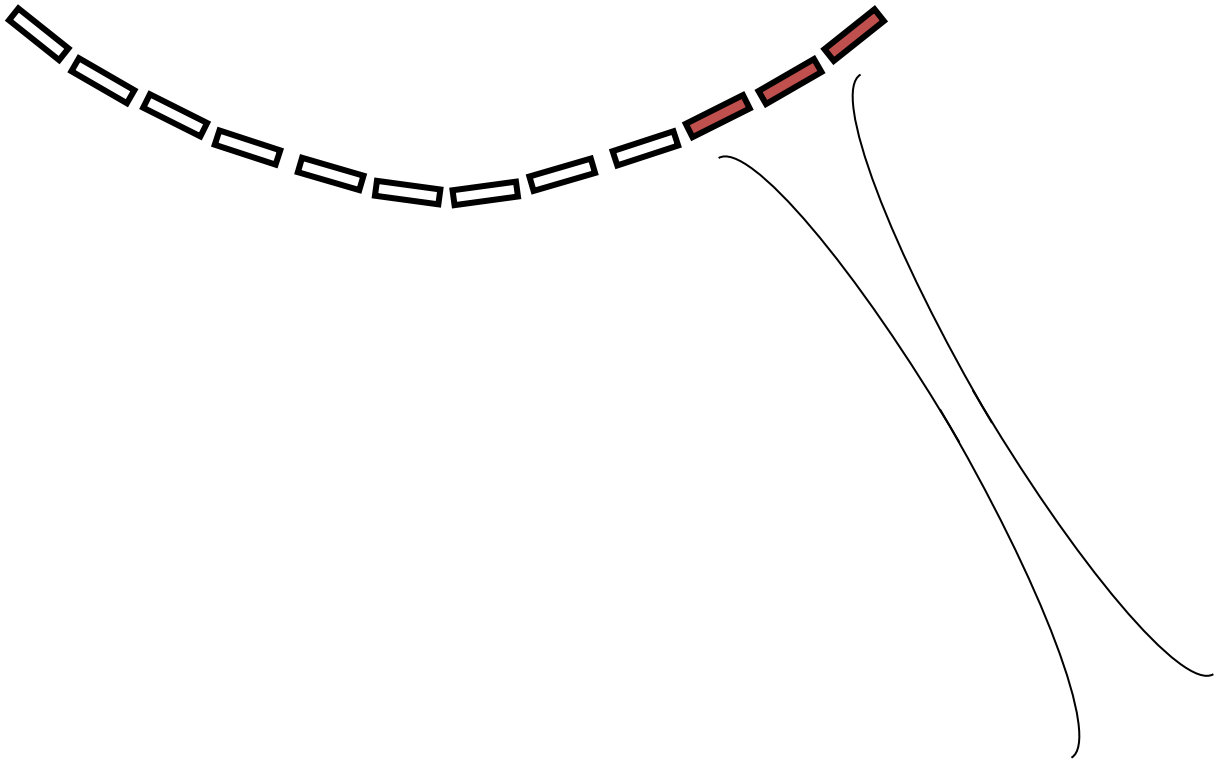
Sectorial scan: convex array



Sectorial scan: convex array



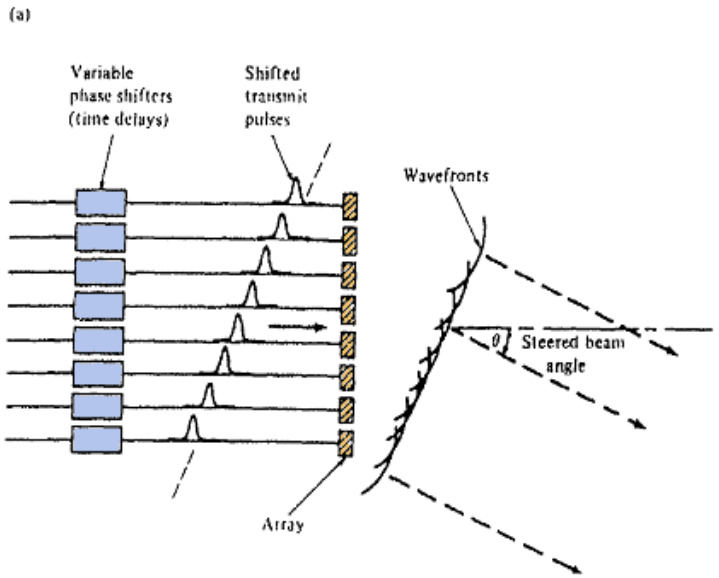
Sectorial scan: convex array

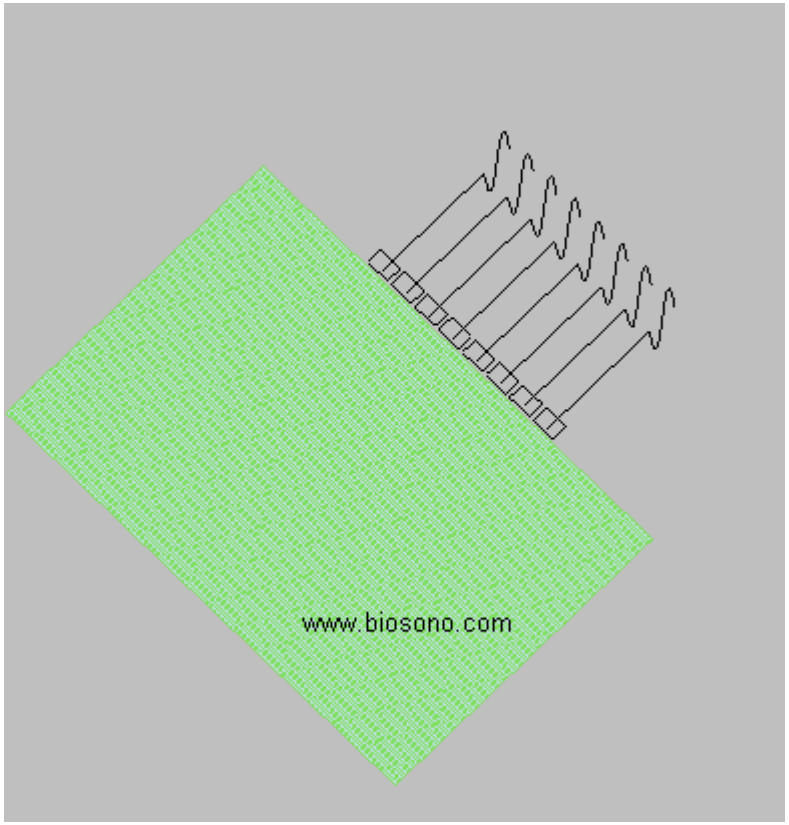


Large field of view but acquisition and representation coordinate systems are different!

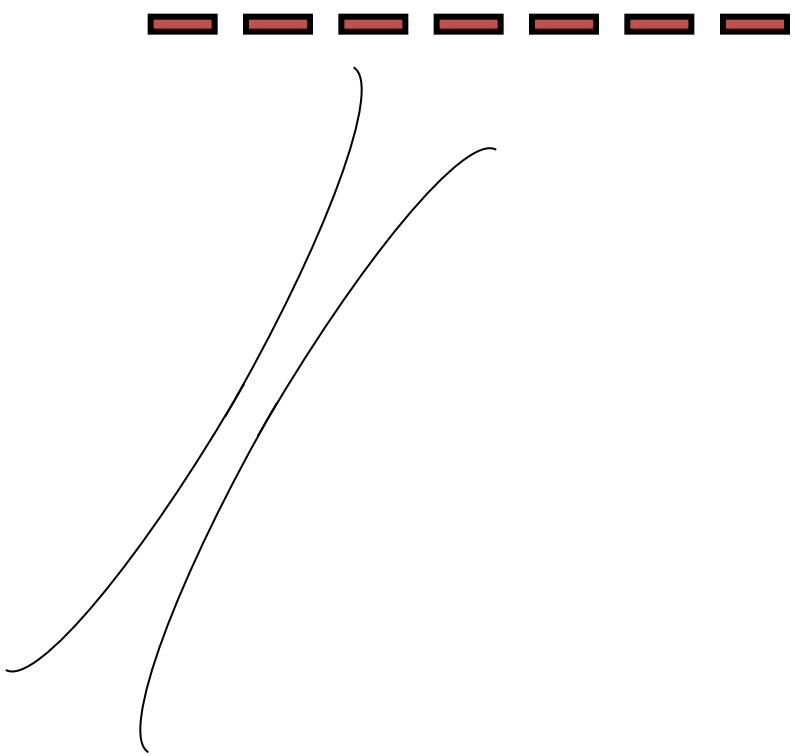
Sectorial scan: steering with a phased array

Delays are used to steer the beam

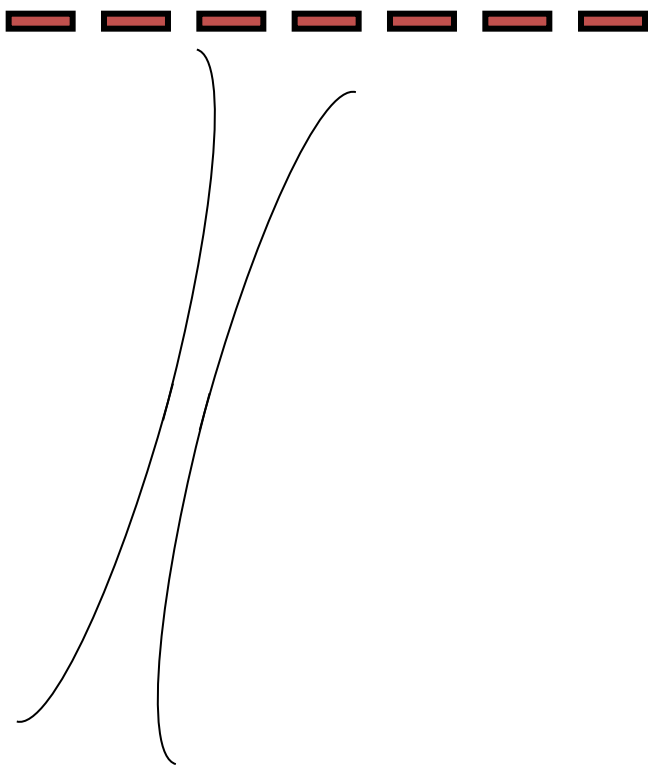




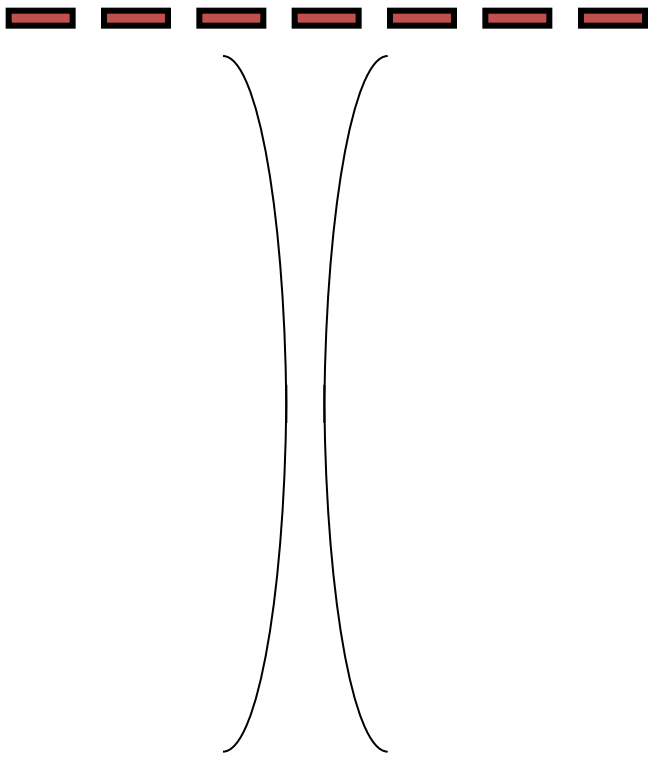
Sectorial scan: steering with a phased array



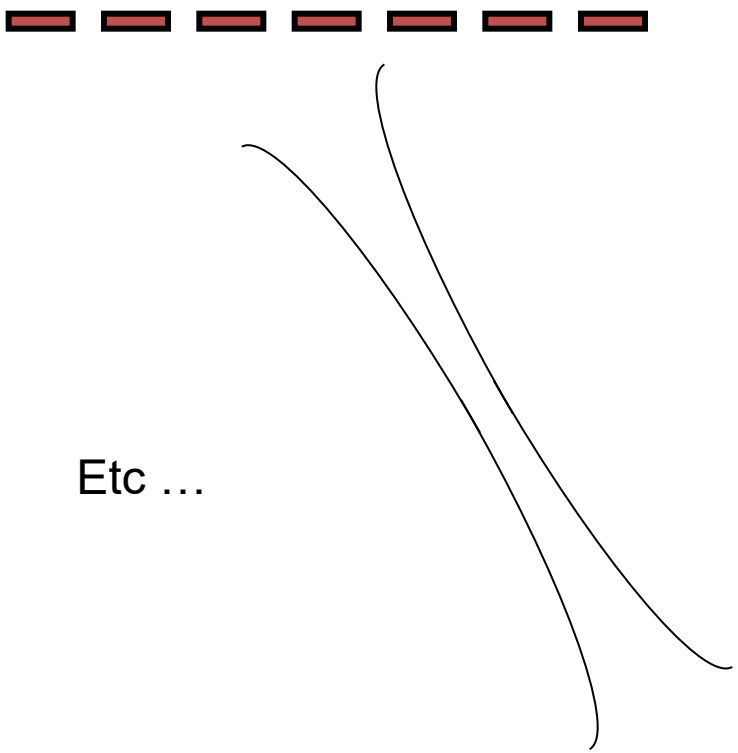
Sectorial scan: steering with a phased array



Sectorial scan: steering with a phased array

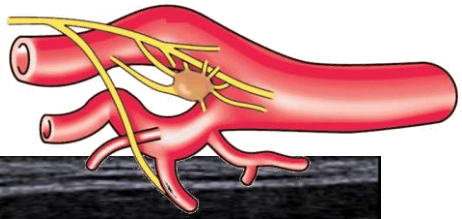


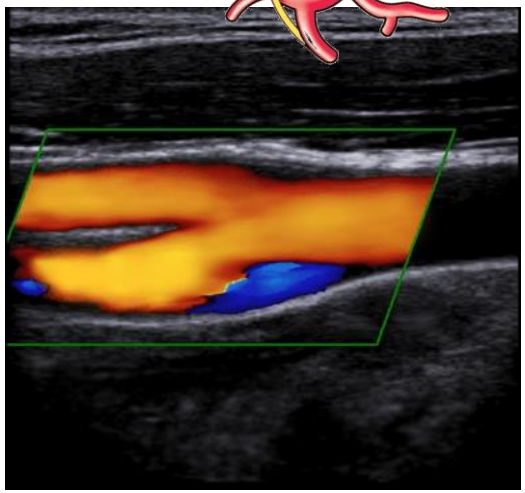
Sectorial scan: steering with a phased array

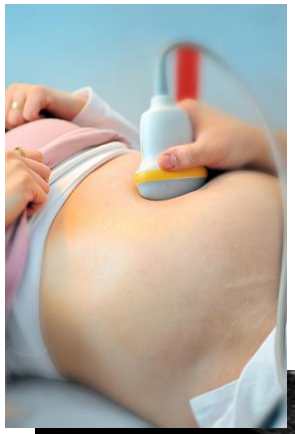


Large field of view from a small footprint but acquisition and representation coordinate systems are different!

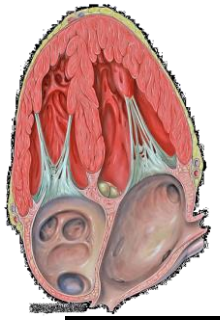
Linear scan



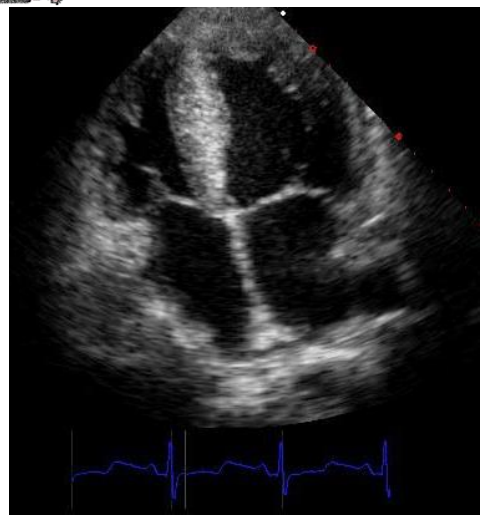












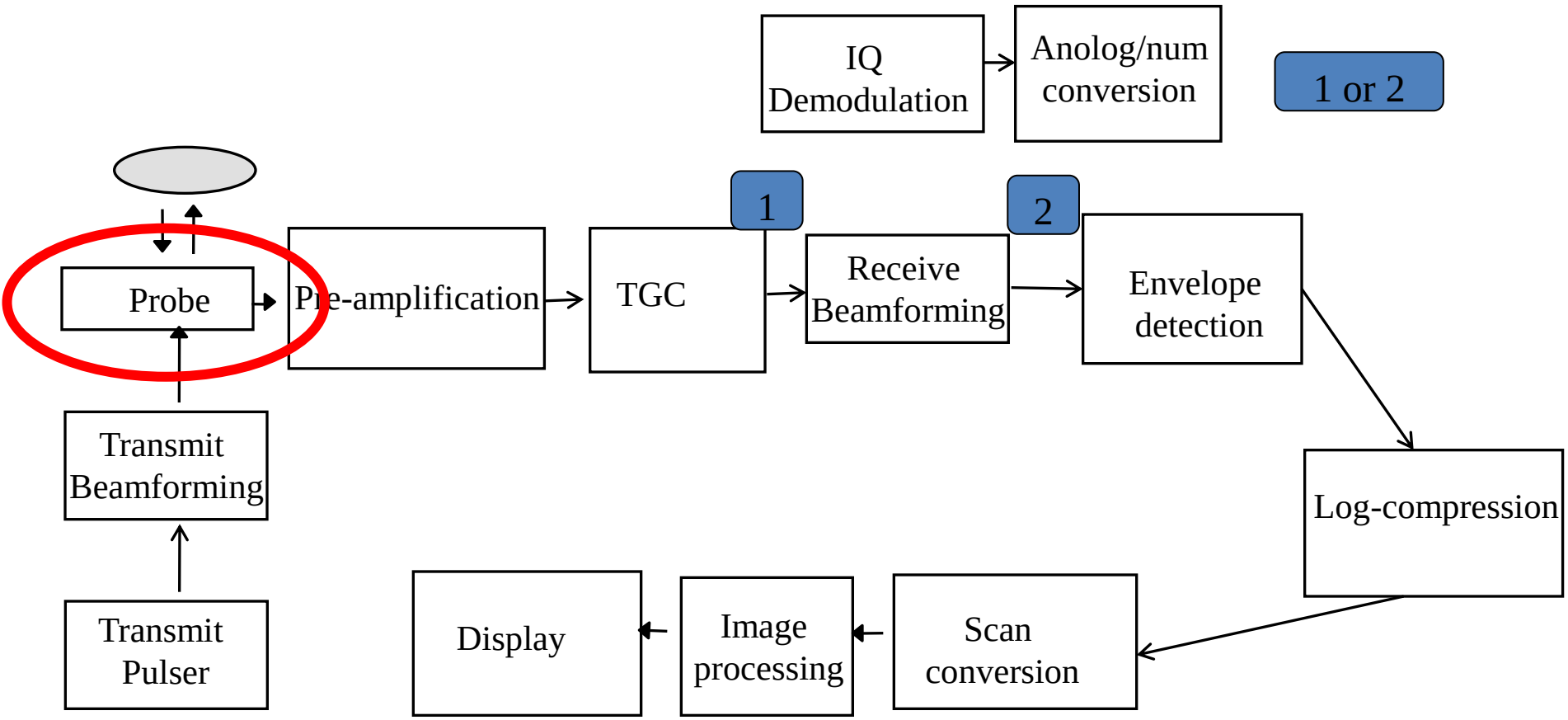
Sectorial scans:

- **abdominal imaging with convex array**
- **cardiac imaging with phased array**

In which coordinate system should we estimate the motion ??

In general in the acquisition coordinate system

All steps to construct an image: inside the ultrasound system



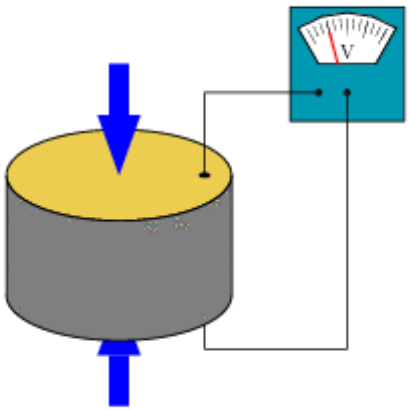
Probes to produce and collect ultrasound waves

The probe is the sensing part of the system

It is used in transmit and receive

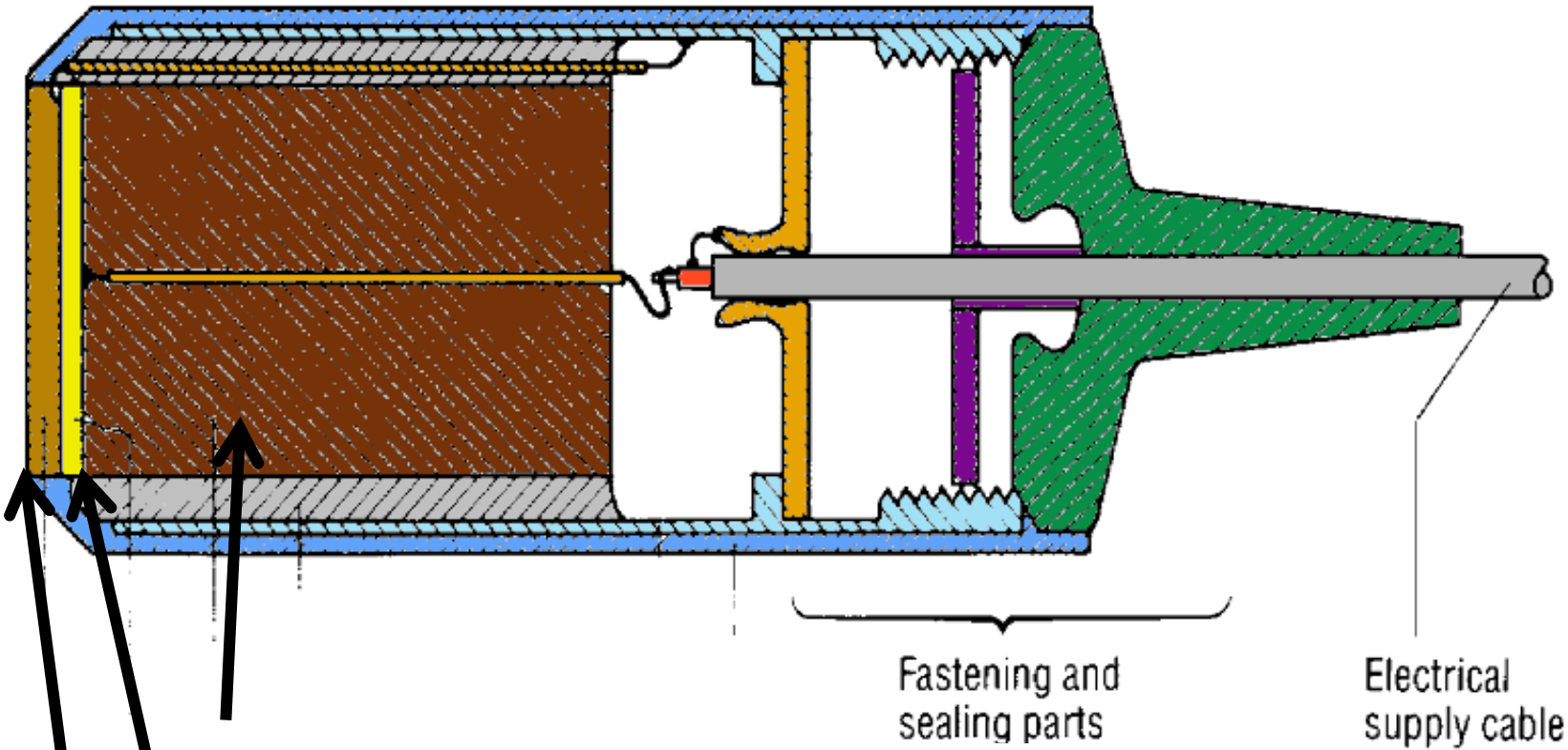
- in tx: electrical energy is transformed into acoustical energy
- in rx : acoustical energy is transforme into electrical energy

The probe material is typically a piezoelectric material



www.wikipedia.fr

Structure of a transducer



« Backing » (absorbing media)

Piezo

Adaptation to skin ($\lambda/4$ layer)

Important frequency caracteristics

Central frequency f0

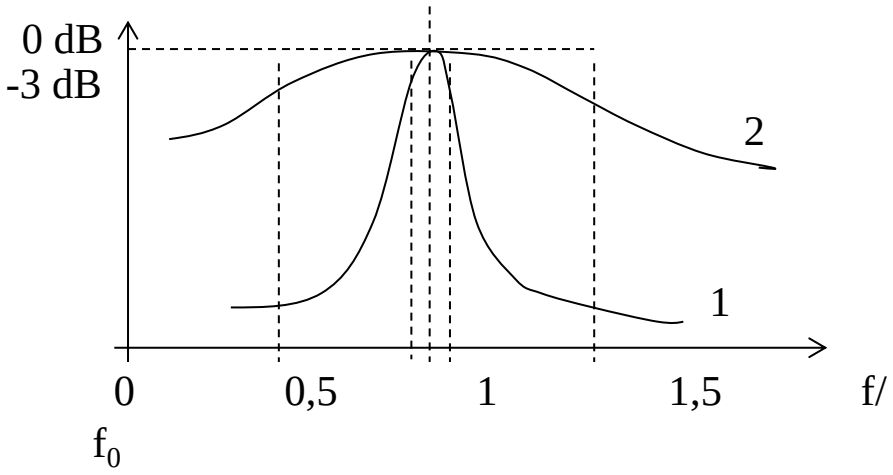
Bandwidth BW

Sometimes given as the **fractional bandwidth** = BW/f0 in %

Frequency response = Fourier transform of the impulse response

(1) narrow band

(2) large band



Important: higher frequency → better resolution but lower penetration depth

Abdominal

- Requisites:
  - Deep penetration
  - Wide field of view
  - Moderate footprint
- Solution:
  - Low frequency
  - Convex probe



Cardiac

- Requisites:
  - Good penetration
  - Wide field of view
  - Very small footprint
- Solution:
  - Low frequency
  - Phased array probe



Vascular

- Requisites:
  - Good resolution
  - Moderate penetration
  - Doppler flow imaging
- Solution:
  - Medium frequency
  - Linear probe



Choice of the probe caharacteristics when motion is involved

Central frequency

high → resolution
low → penetration

Bandwidth

large = better resolution

Probe geometry depends of expected field of fiew

linear / convex / phased array

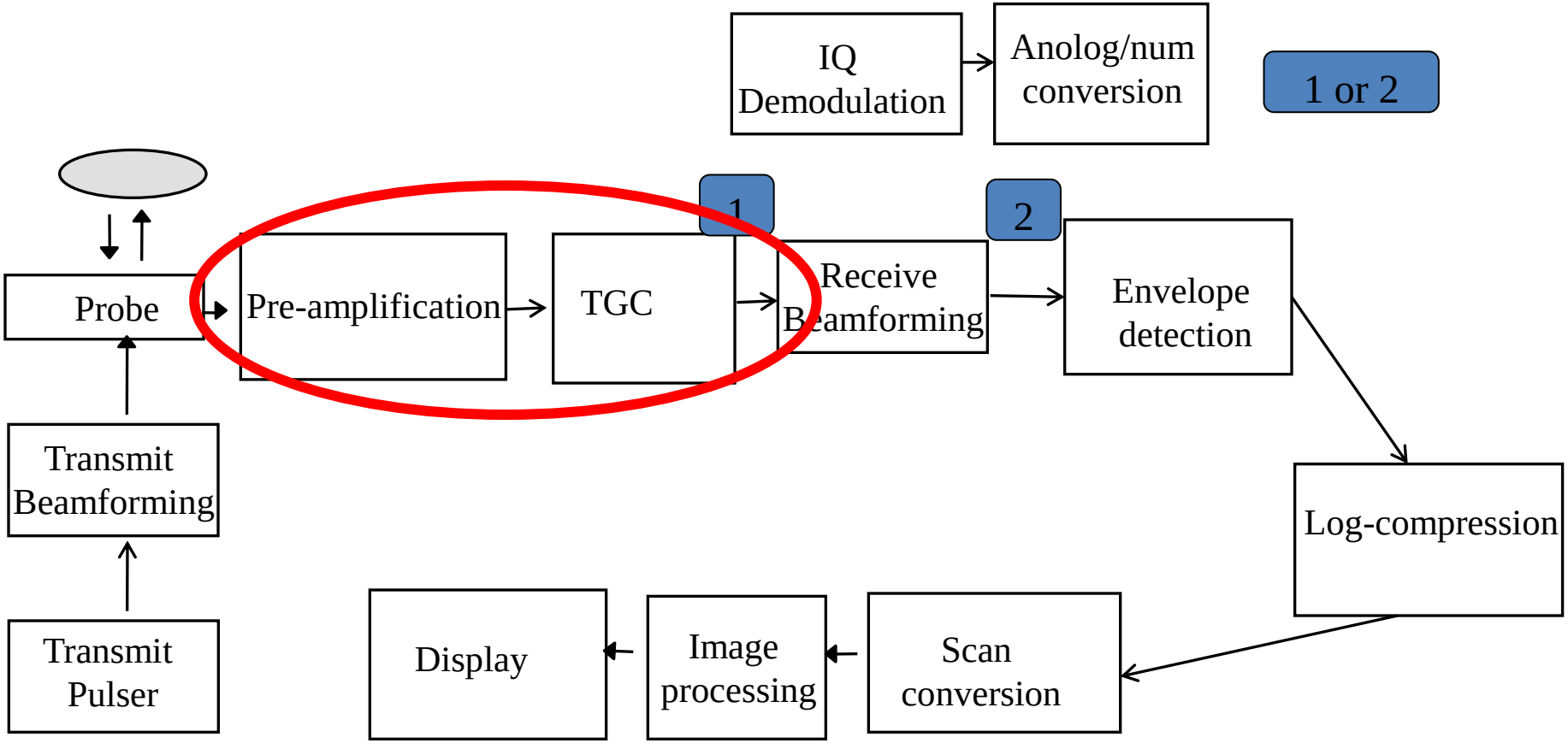
When Doppler techniques should be used

often steering is necessary → pay attention to elements spacing and grating lobes

high velocities cannot be estimated if f0 is too high

(see course on Doppler techniques)

All steps to construct an image: inside the ultrasound system



Preamplification: necessary because **single elements signals have low amplitude**

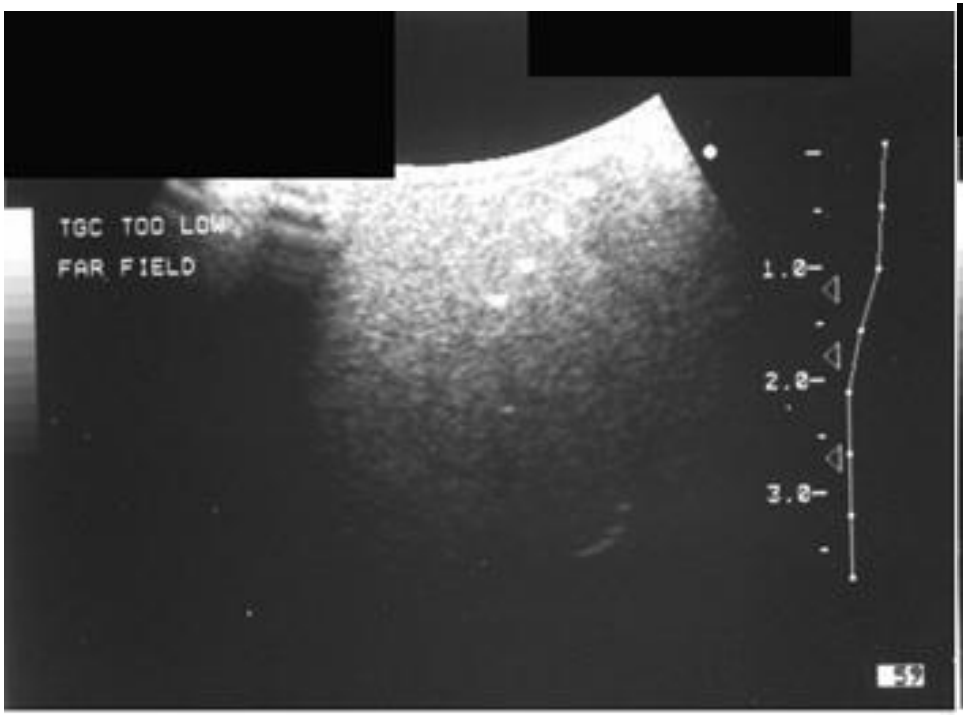
TGG: time gain compensation

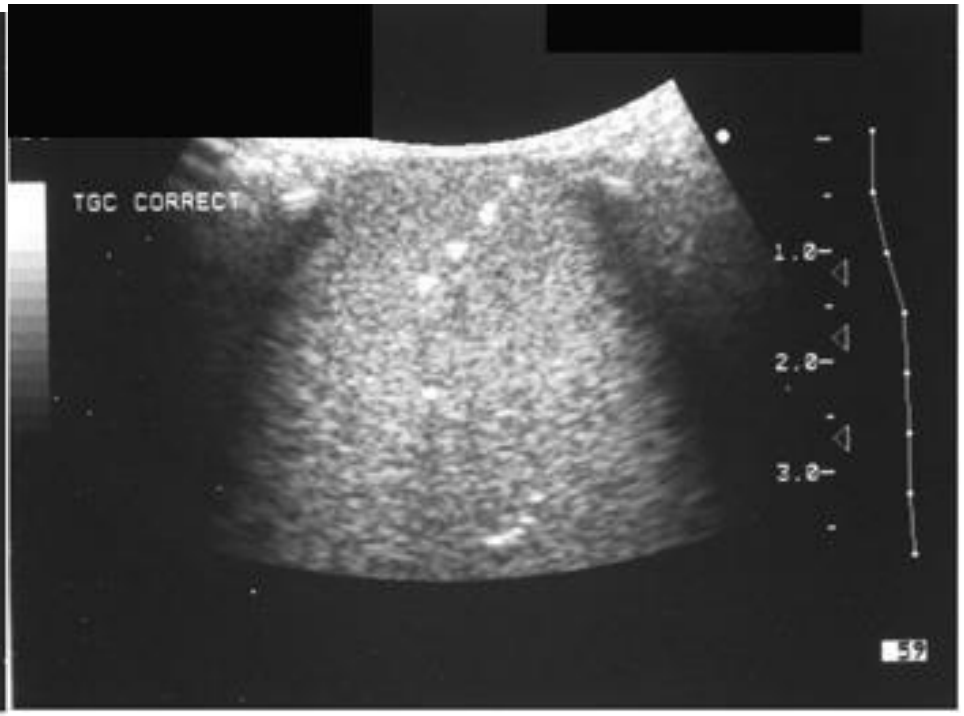
Attenuation depends on propagation depth

Two scatterers at different depths, or one scatterer moving from one depth to another will change appearance

Correction is performed with a time/depth dependant amplification factor







http://www.veterinaryradiology.net

All steps to construct an image: inside the ultrasound system

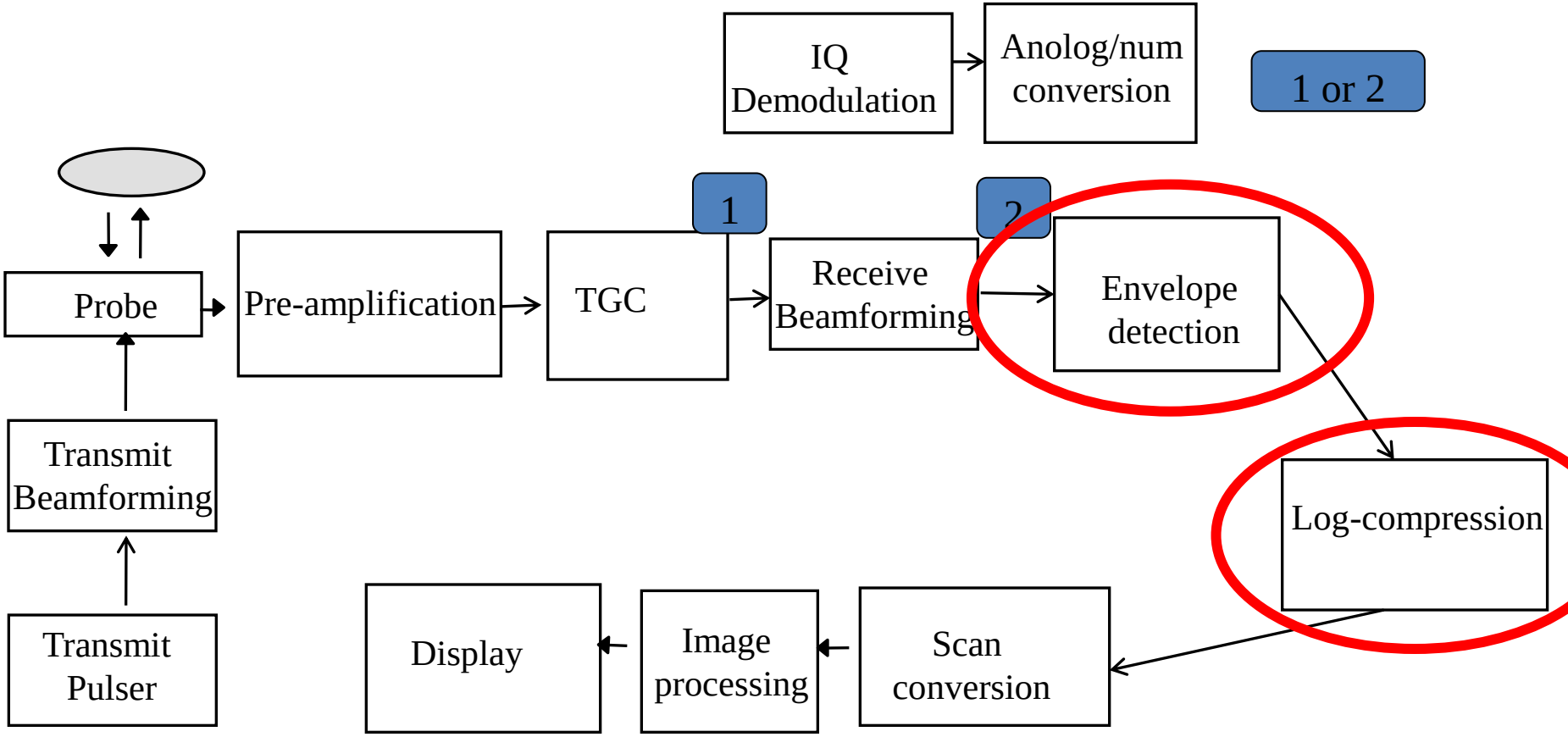
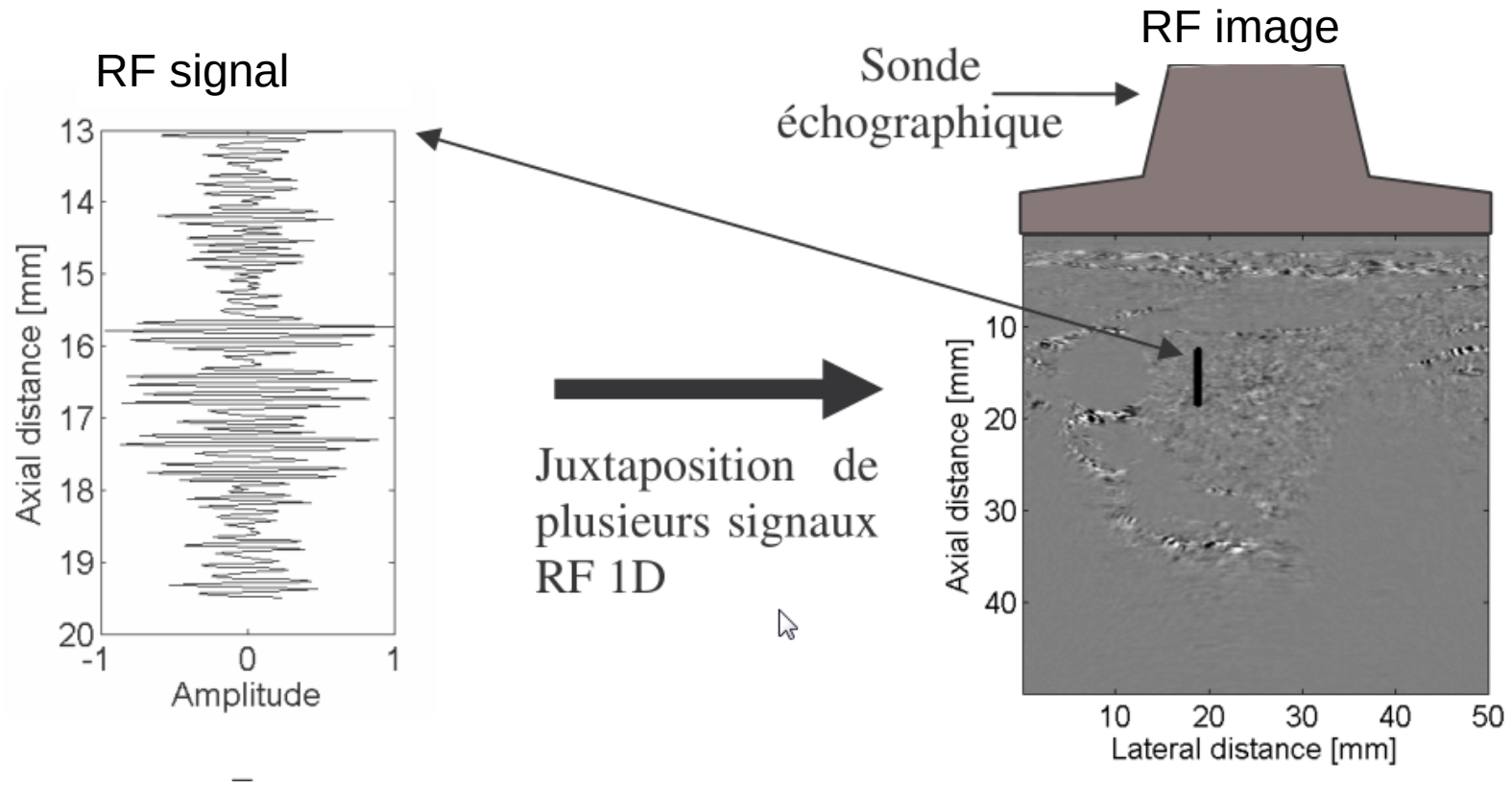


Image without envelope detection: what's the problem?

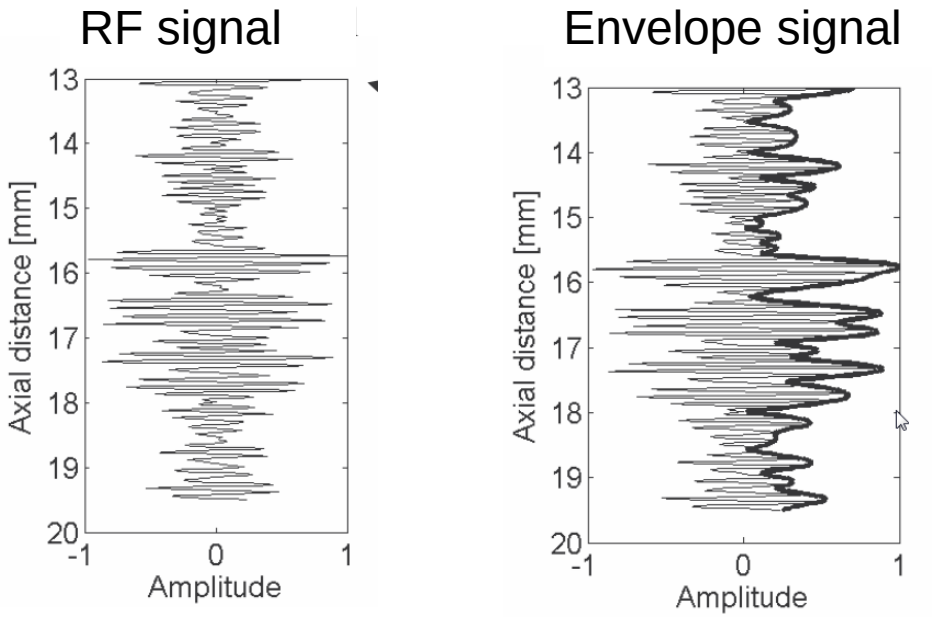


Basarab thesis 2008

Envelope detection

Conventional imaging removes the phase and keeps only the amplitude

$\Rightarrow$ The signal is demodulated to remove the high frequency carrier

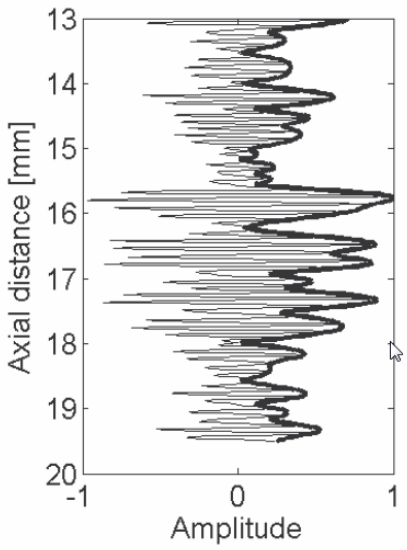


Envelope detection

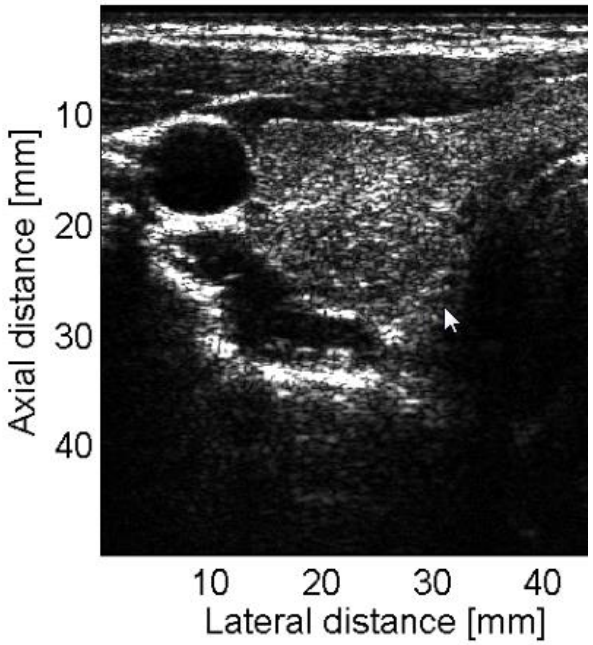
Conventional imaging removes the phase and keeps only the amplitude

$\Rightarrow$ The signal is demodulated to remove the high frequency carrier

Envelope signal



Envelope image



Log compression

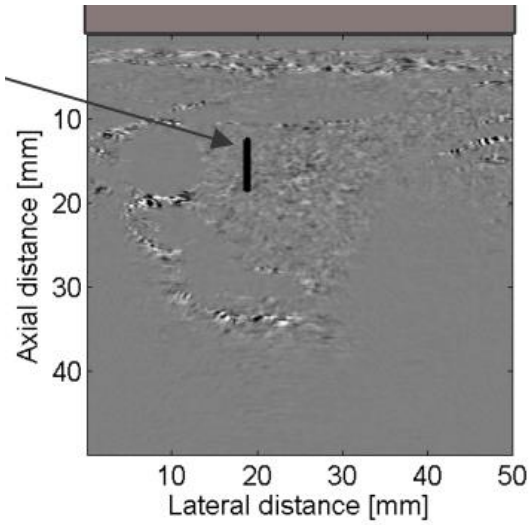
In a same image very strong echoes due to interfaces and weak echoes from the soft tissues of interest are present

The RF signal has a dynamics around 100 dB (ratio 1/100000)

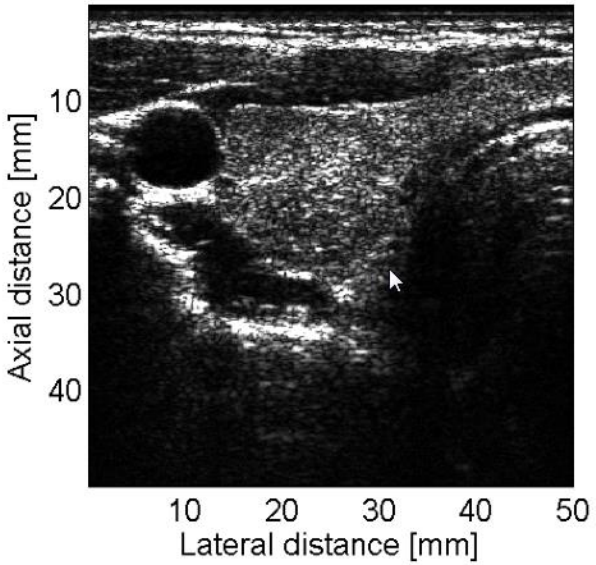
The human eyes can differentiate 25 to 30 dB

⇒ A log compression is performed before visulalisation

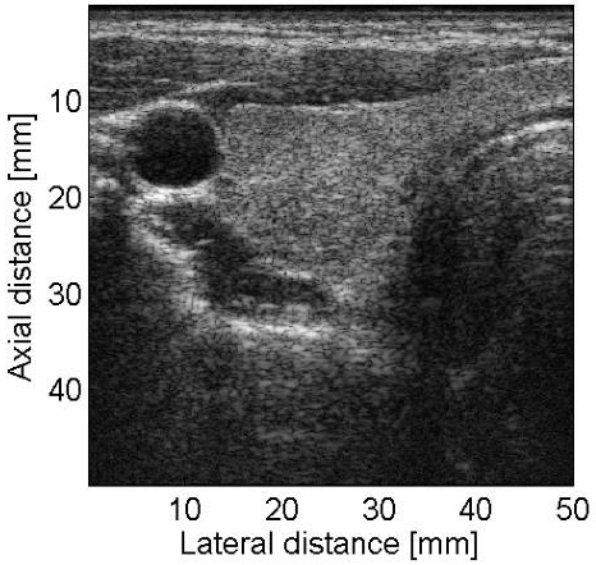
RF image



Envelope image



Log-compressed or B-mode image



Which signals / images to use for motion imaging?

RF signals are centered around a central frequency

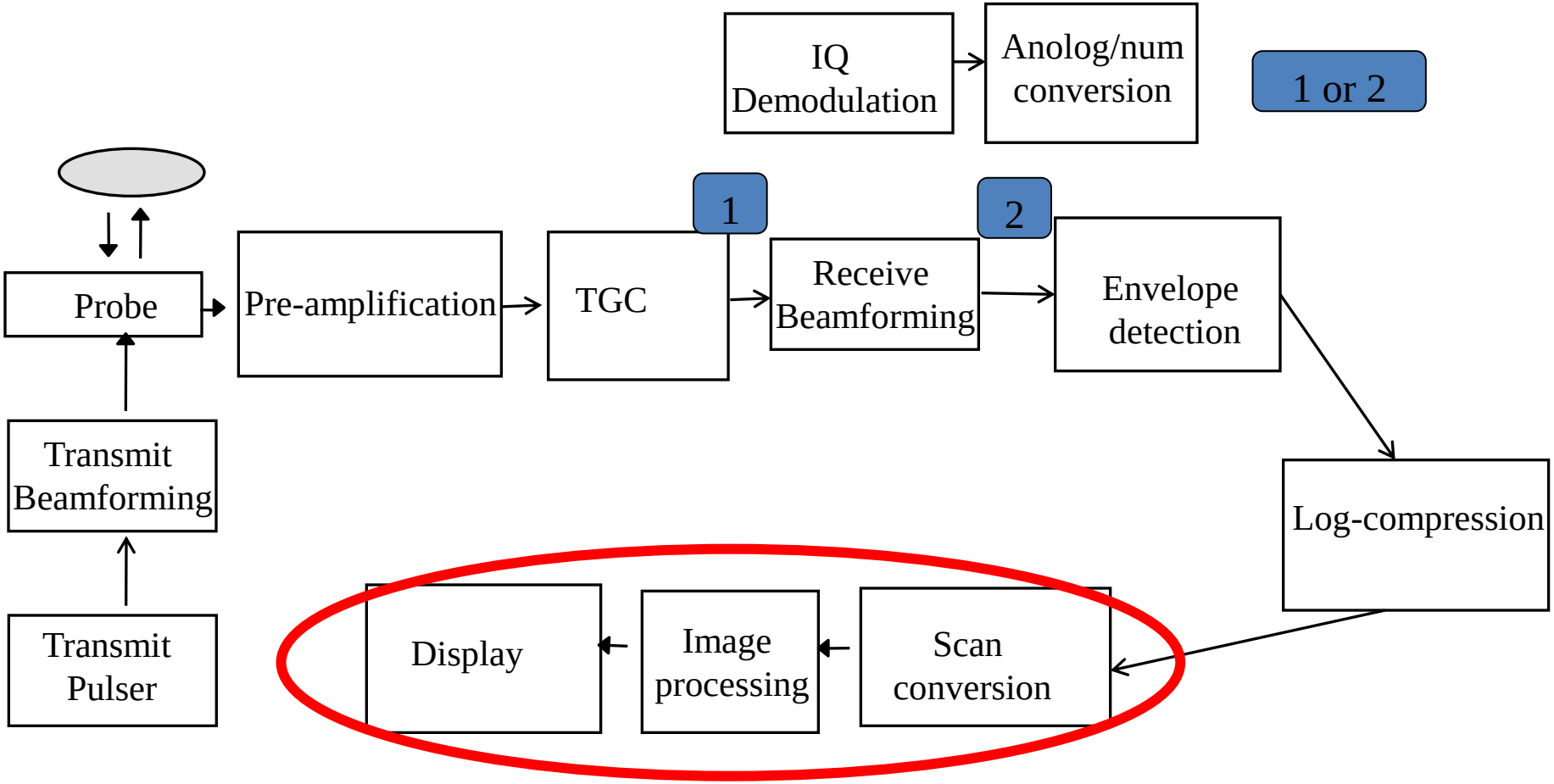
preffered signals for Doppler techniques (see also IQ signal)

More variations in the RF signals might seem better for bloc matching (correlation) techniques but

for large displacement (high velocities) → envelope

for small displacements (low velocities) → RF

All steps to construct an image: inside the ultrasound system



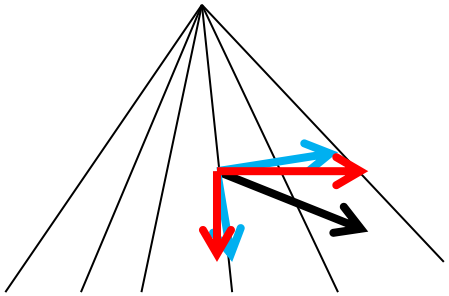
Scan conversion / image processing /display

when the beam is steered and all lines are not alined in a cartesian coordinate system

the scan is sectorial and this conversion is necessary **before display** to ensure no geometrical distortion

This step can necessitate **interpolation**

Projections of the estimated motion field can also be necessary if the estimation coordinate system is different from the display coordinate system



True motion
Sectorial coordinates
Cartesian coordinates

A few notions more

Speckle / resolution cell

The resolution cell is the smallest volume of interest inside which scattering strcutures cannot be differentiated

Dimension of the scatterers are smaller than the wavelength and smaller than the resolution cell

The echoes are the result of an inteference pattern

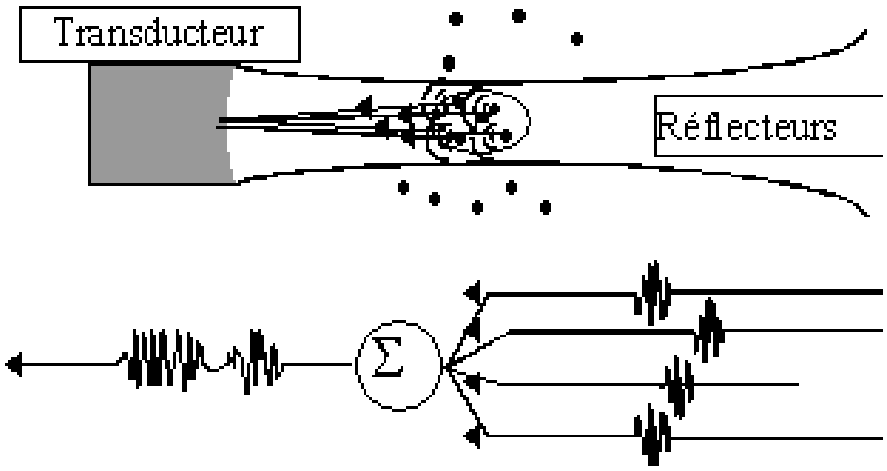
Piezoelectric elements also integrate several echoes simultaneously

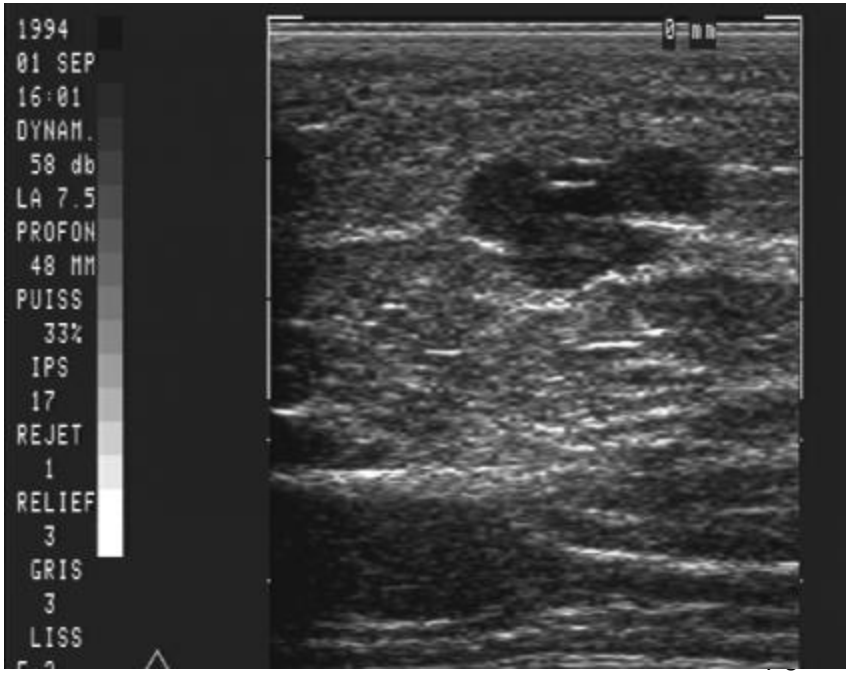
The contribution from scatterers inside the resolution cell cannot be differentiated

Speckle can be considred noise, but it carries information (sometimes used to characterize tissues, perform segmentation)

Speckle dépends on structure of the tissue (density, size, distribution of the scatterers) AND imaging parameters (focusing central frequency excitation pulse, etc..)

It leeds to the granular strcuture of images





Estimation motion by following speckle patterns

Common assumption :

Speckle pattern modification render exactely tissue modification
→True for rigid motion inside the imaging plane

This assumption can be corrupted due to:

out of plane motion
different velocities inside the resolution cell
deformation / acceleration

Sometimes contrast agents are injected to follow single scatterers (bubbles) in the image sequence.

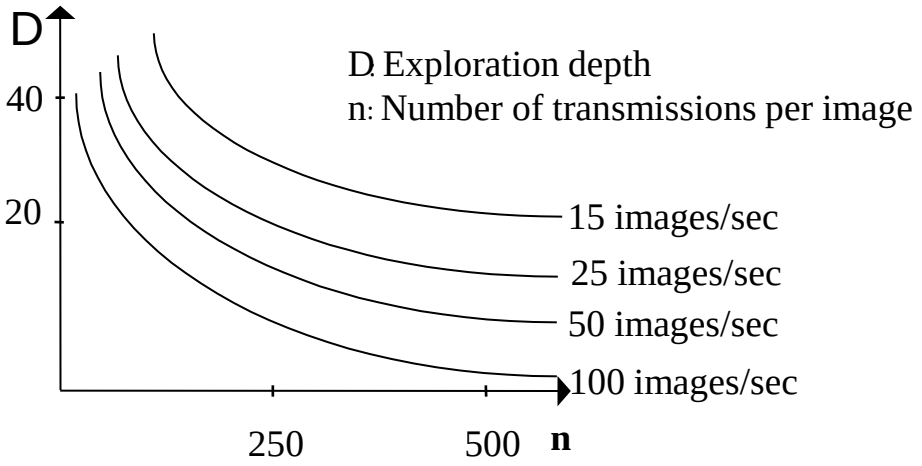
→ Echo PIV (particule imaging velocimetry)

Frame rate

The frame rate is linked to the temporal sampling rate

$$T_{PRF} \leq \frac{c}{2P}$$

$$\text{FR} = \frac{T_{PRF}}{n} \leq \frac{c}{2nP}$$



Increasing the spatial sampling rate (more lines) goes with

a decrease in exploration depth

a decrease in frame rate

There is no need to increase the number of lines beyond the physical reslution (PSF size)

Consequences of frame rate or PRF miss adjustments

In Doppler techniques

too low PRF might lead to aliasing

In Speckle tracking approaches

low PRF → deformed appearance (rolling shutter artefact)

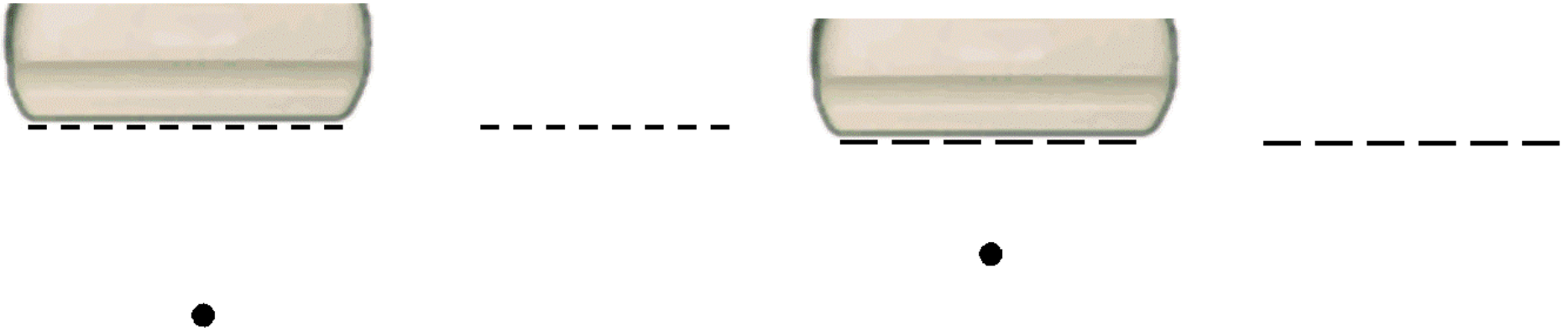
low frame rate → too high interframe motion

high frame rate → undetectable / subpixel interframe motion

➔ Need for a compromise

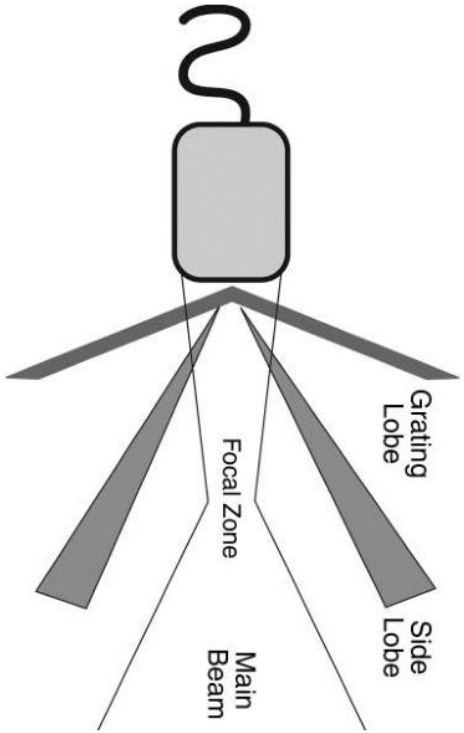
Some solutions exist to accelerate the frame rate: plane wave imaging

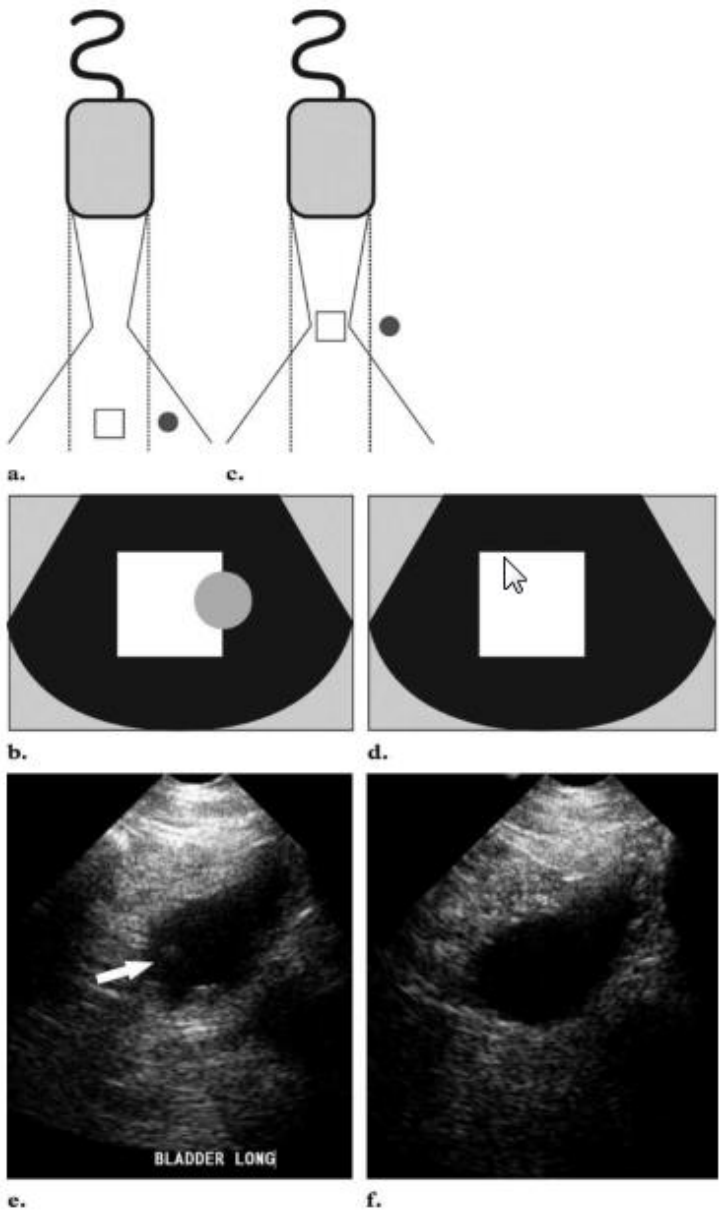
High Frame rate plane wave acquisition



Some artefacts illustrations and possible consequences on motion imaging

Θ ***Due to side lobes → the wrong motion can be imaged***

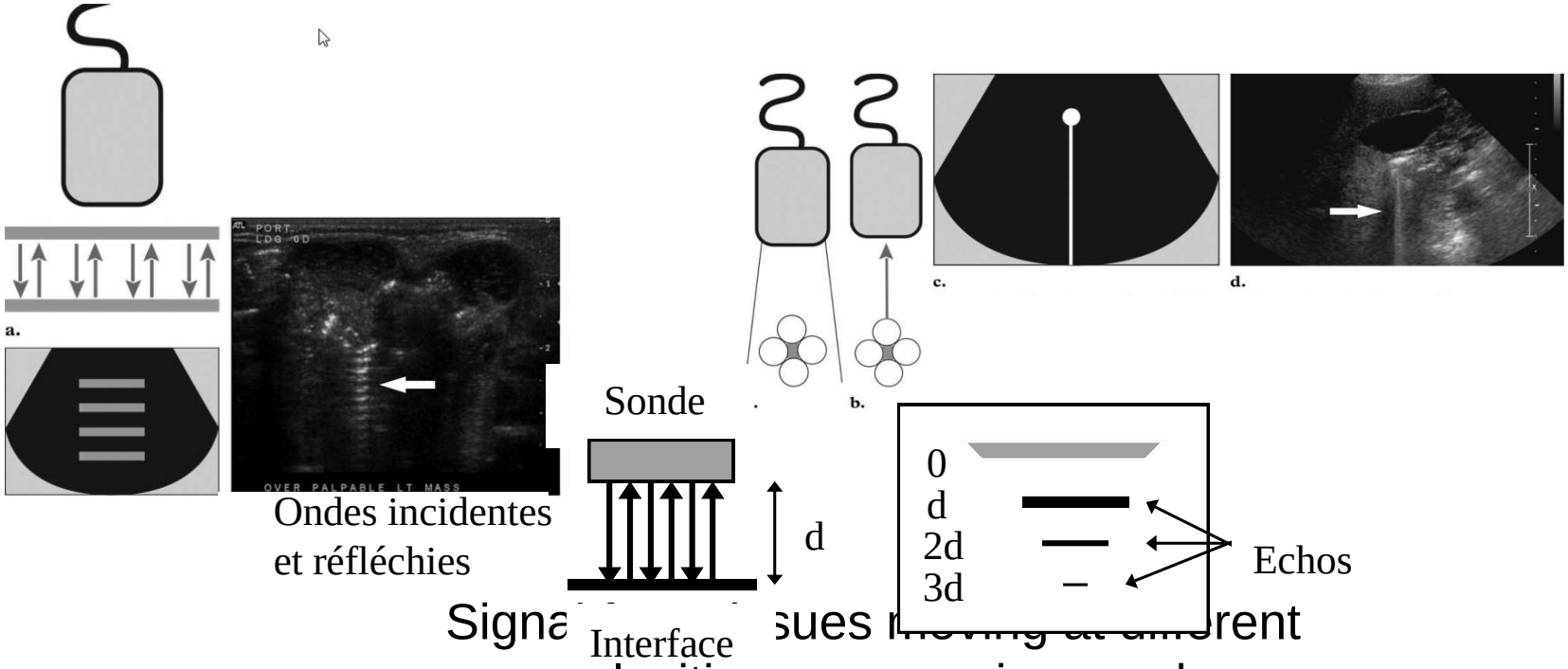




Some artefacts illustrations and possible consequences on motion imaging

Θ *Multiple echoes / ring down*

Due to a strong interface or a reverberating inclusion

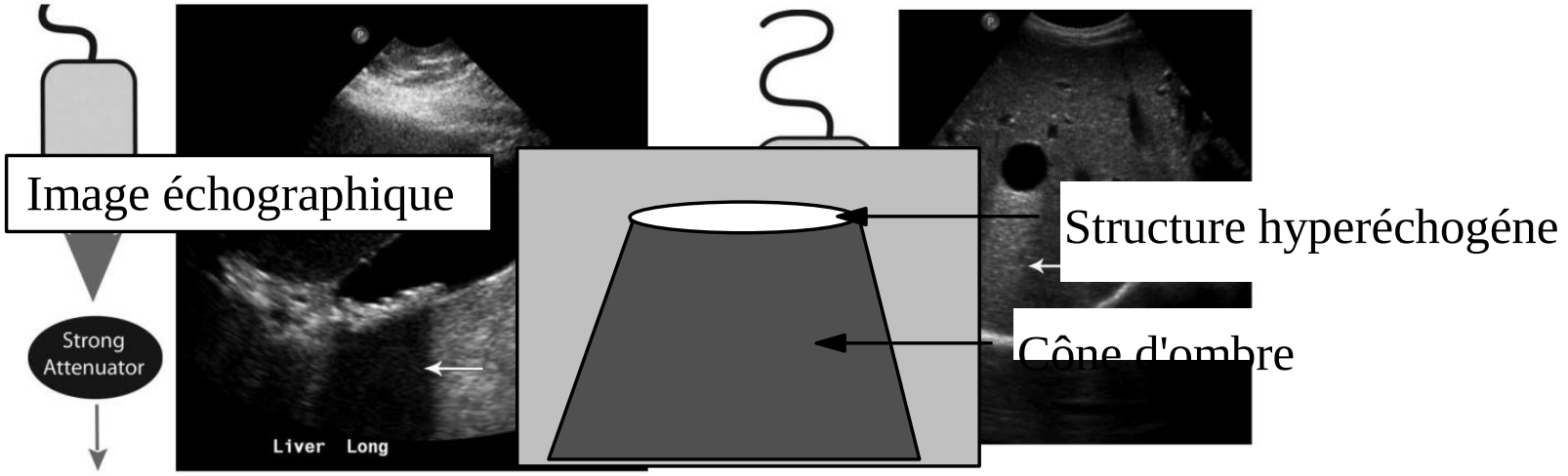


Signa sues moving at different velocities are superimposed

Θ *Shadow / hypo-echoic regions*

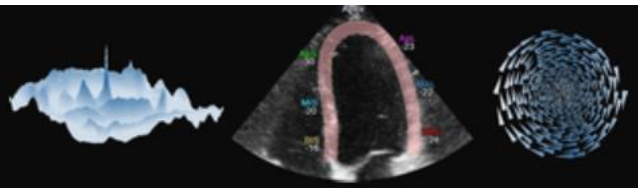
A highly reflecting structure hides the tissue behind it

Or a poorly attenuating media leads to higher intensities behind it



Velocities might be un-estimable in the shadow behind a higly reflecting structure

Changes in intensity might be interpretad by an algorithm as motion



Generate images from sound

Hervé Liebgott

Prof. University of Lyon

CREATIS

22/04/2019

Thank you for your attention!