Detection in ultrasound

Paul Liu

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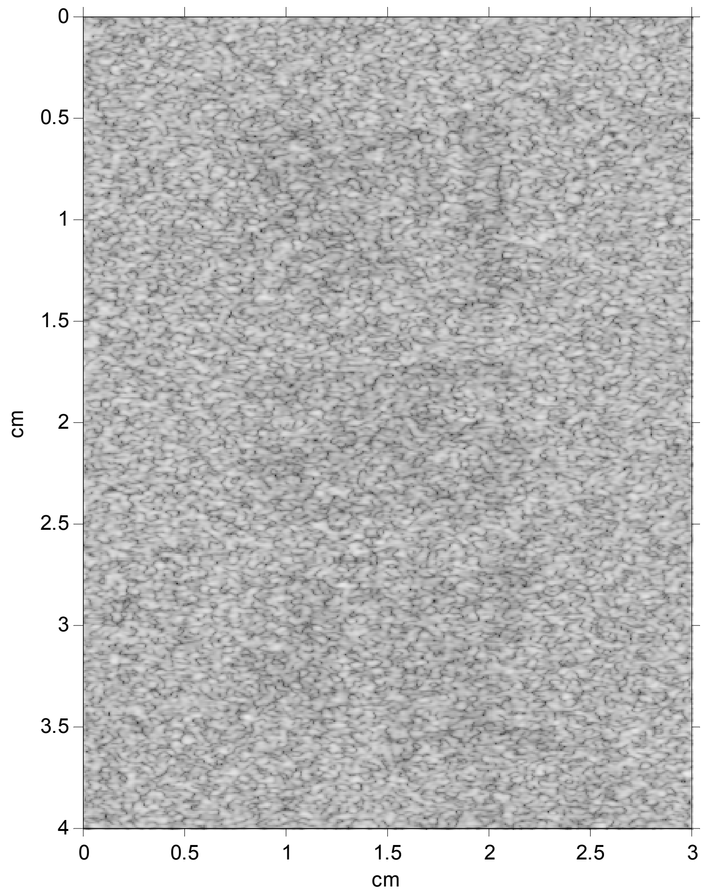
Background

- In an ultrasound image, define a *target* as a cyst, lesion, or other object (possibly small)
- Question: Is there a target inside the ultrasound image?

Example: Is there something in this image?

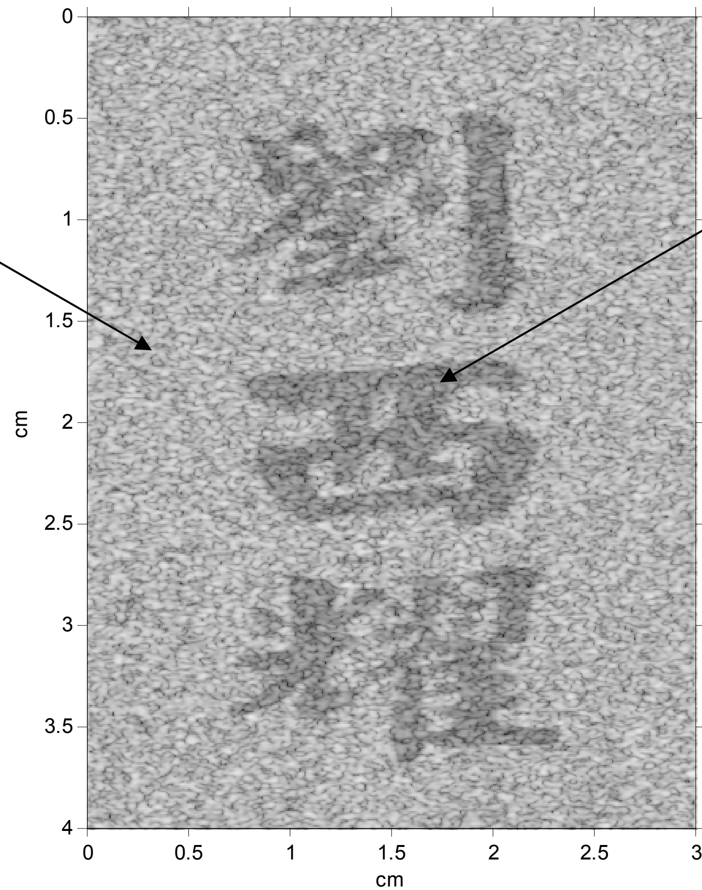


60 db log transformed display

Example: What about now?

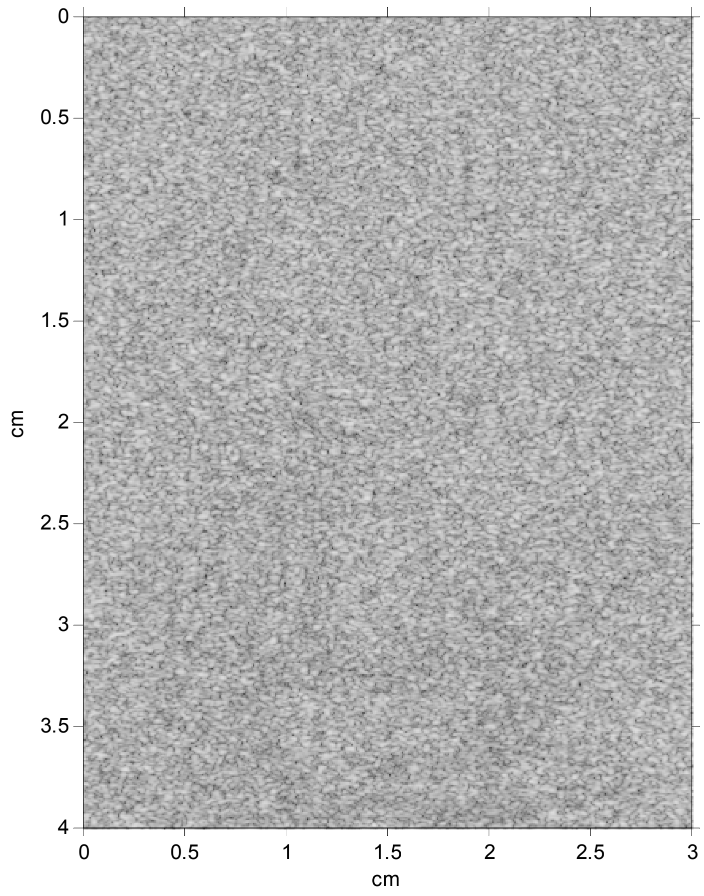
background

target

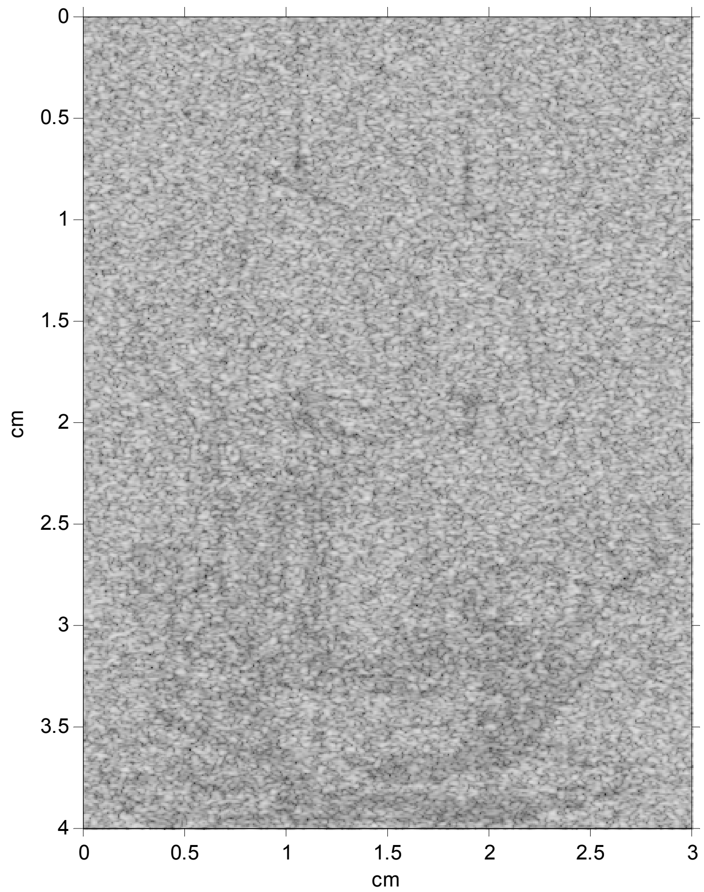


Previous image target was at -3db (0.71) of background brightness
This image is at -10db (0.31)

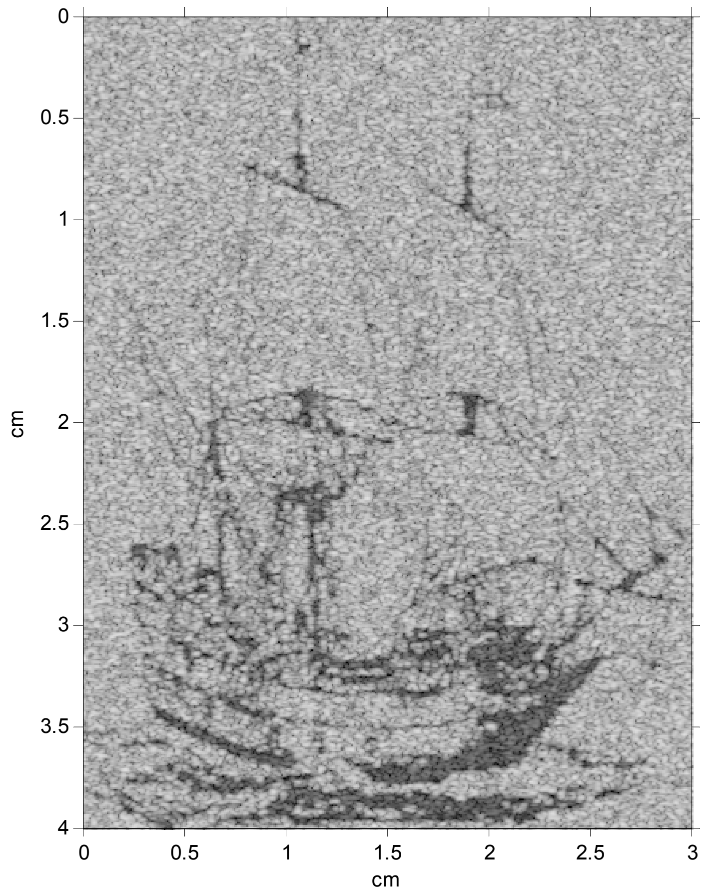
A harder example. What about this pic?



Should be clearer now (-6 db contrast)



-20 db contrast



On the image simulation

- All images are simulated by convolution of random scatterers with a point spread function
- Scatterers are located in a fixed (fine) rectangular grid. Their reflection is a random uniform variable between 0 and 1
- The random scatterers are then multiplied by a reflectivity image

Detection problem

- Define the following problem:
  - An observer decides on *two* hypotheses
  - H_1 : target exists in image 1 but not in image 2
  - H_2 : target exists in image 2 but not in image 1
- The optimal solution is the ideal observer proposed and discussed in:
  - Smith, Wagner, et al. “Low Contrast Detectability and Contrast/Detail Analysis in Medical Ultrasound,” IEEE Trans. Sonics Ultrasonics, 1983
  - Insana and Hall. “Visual detection efficiency in ultrasonic imaging. A framework for objective assessment of image quality,” JASA, 1994

H_1: Image 1 and image 2 backgrounds are independent

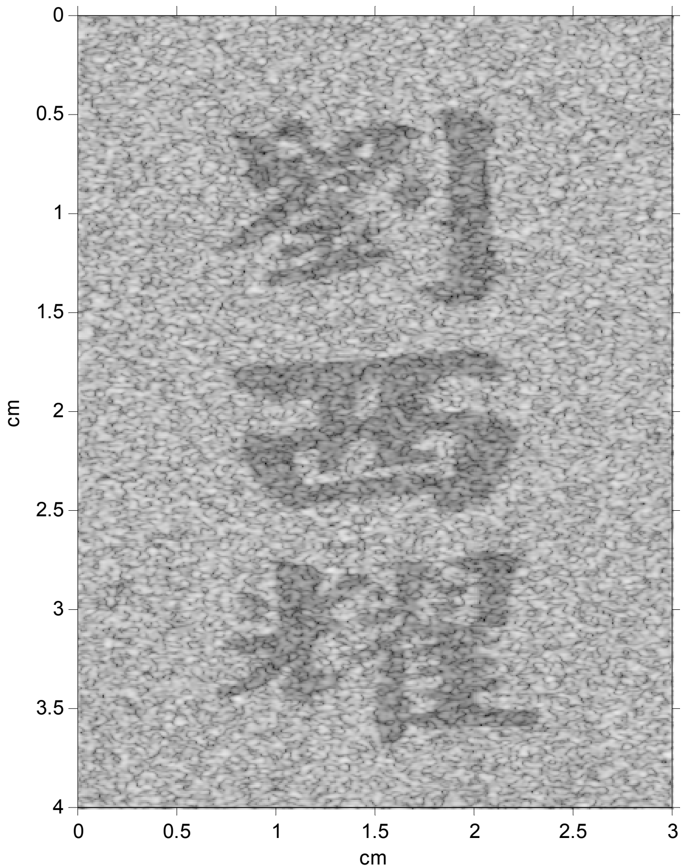


Image 1

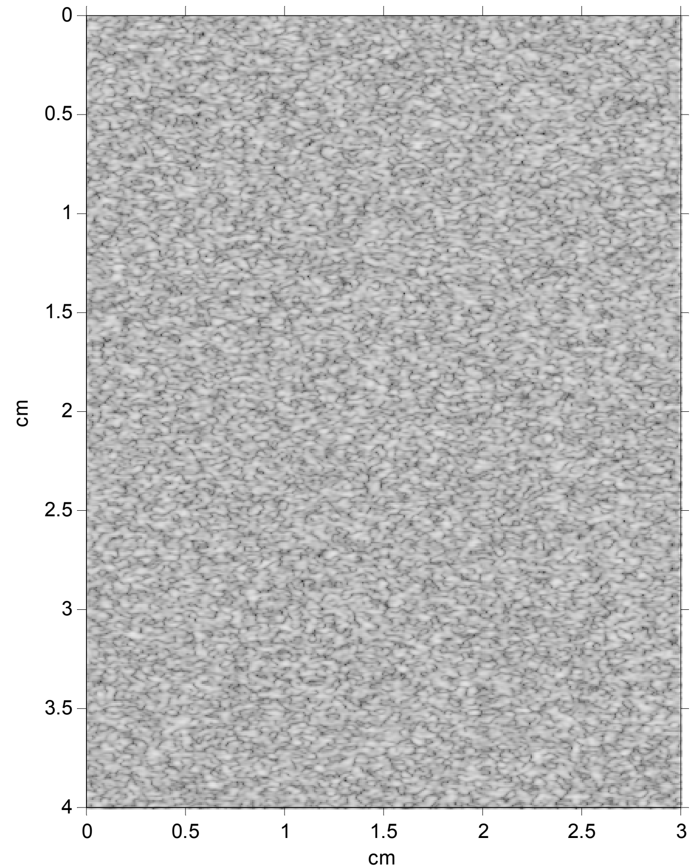


Image 2

H_2: Image 1 and image 2 backgrounds are independent

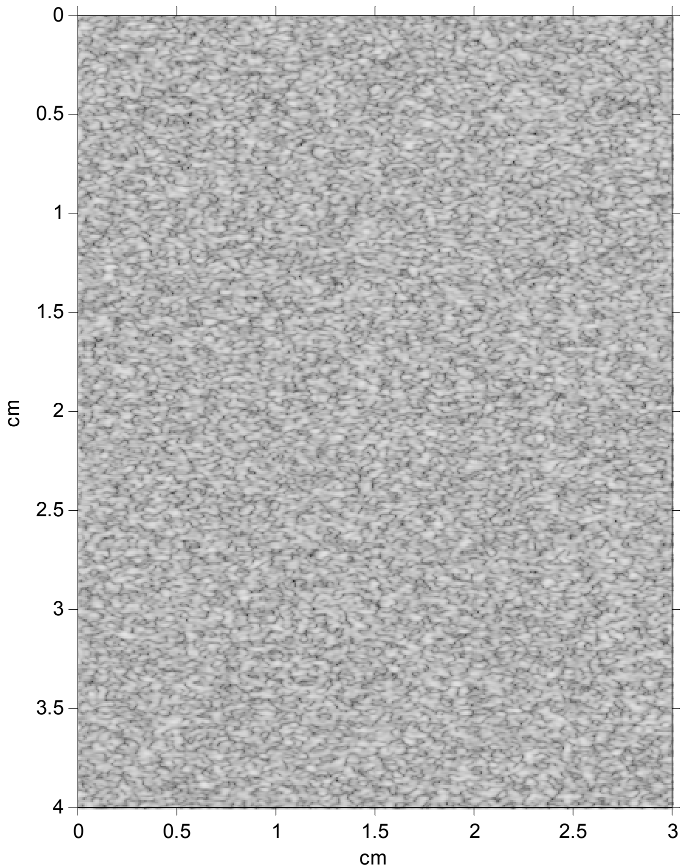


Image 1

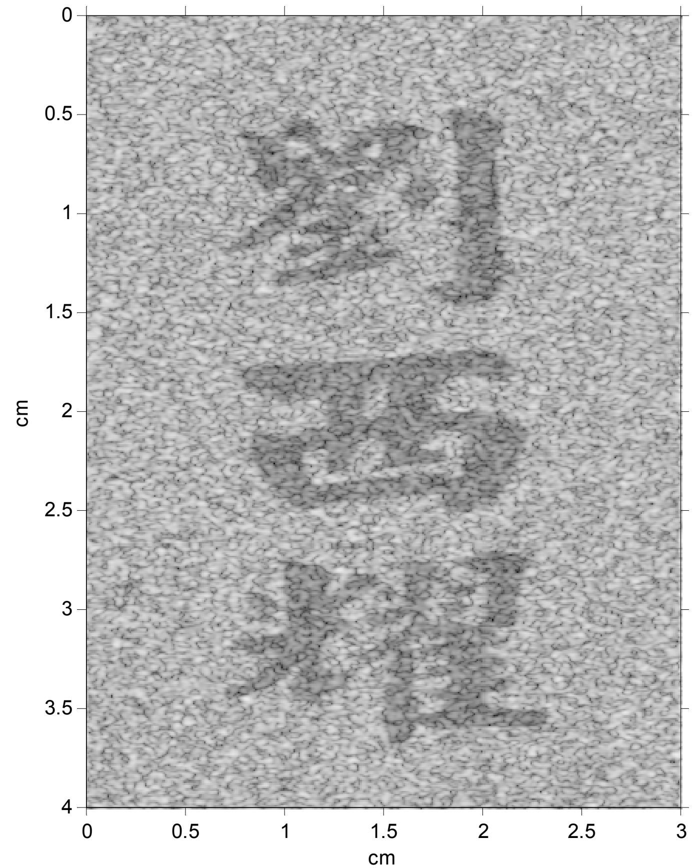
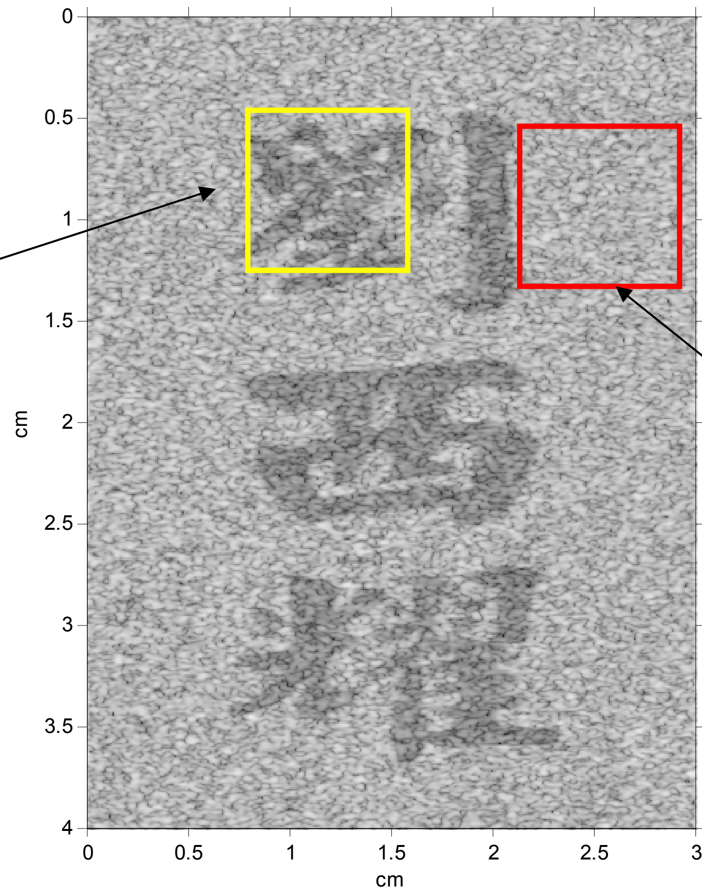


Image 2

Note the definition of “images”



Can call this “image 1”

Can call this “image 2”

Detection

- Let y_1 and y_2 be the envelope of image 1 and 2 respectively
- Let $p(y_1, y_2 | H_1)$ and $p(y_1, y_2 | H_2)$ be the joint probability distribution function (pdf) under each hypothesis
- Then from detection theory the decision function is the likelihood ratio

$$D' = \frac{p(y_1, y_2 | H_1)}{p(y_1, y_2 | H_2)}$$

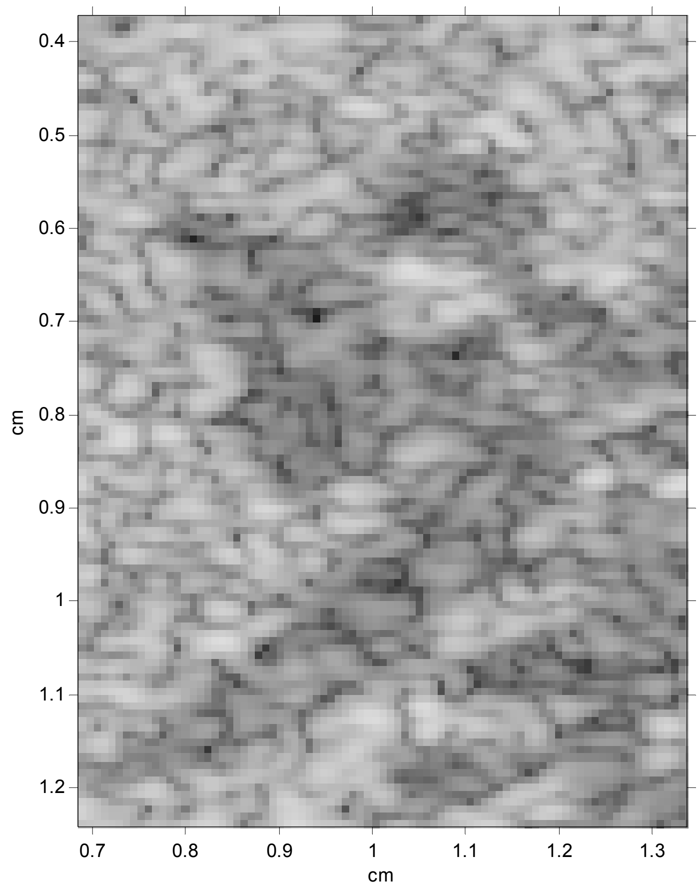
Decision function

- After these steps:
  - Assume fully developed speckle (Rayleigh distribution of envelope)
  - Take a scaled version of the log of the likelihood function (this is valid as long as the function is monotonic)
- Then the decision function D is

$$D = \sum_{i=1}^{M} y_{1i}^2 - \sum_{j=1}^{M} y_{1j}^2$$

  - where summation is taken by sampling M *independent* samples
- If the target is lower brightness than background, we decide that target exists in image 1 if D < 0. Otherwise, we decide that target exists in image 2

Zoomed in. Notice the correlation of the speckle



Number of independent samples M is proportional to the number of speckle spots

How well can we detect?

- The detection ability is determined by

$$SNR = \frac{|E(D|H_1) - E(D|H_2)|}{\sqrt{(\sigma^2_{D|H_1} + \sigma^2_{D|H_2})/2}}$$

  - where E( ) denotes expectation
- This simplifies into
  - SNR = $$2\sqrt{M}\,\frac{\left|\psi_t - \psi_b\right|}{\sqrt{\psi_t^2 + \psi_b^2}}$$
  - where ψ_t and ψ_b are the mean square averages of the target and background respectively

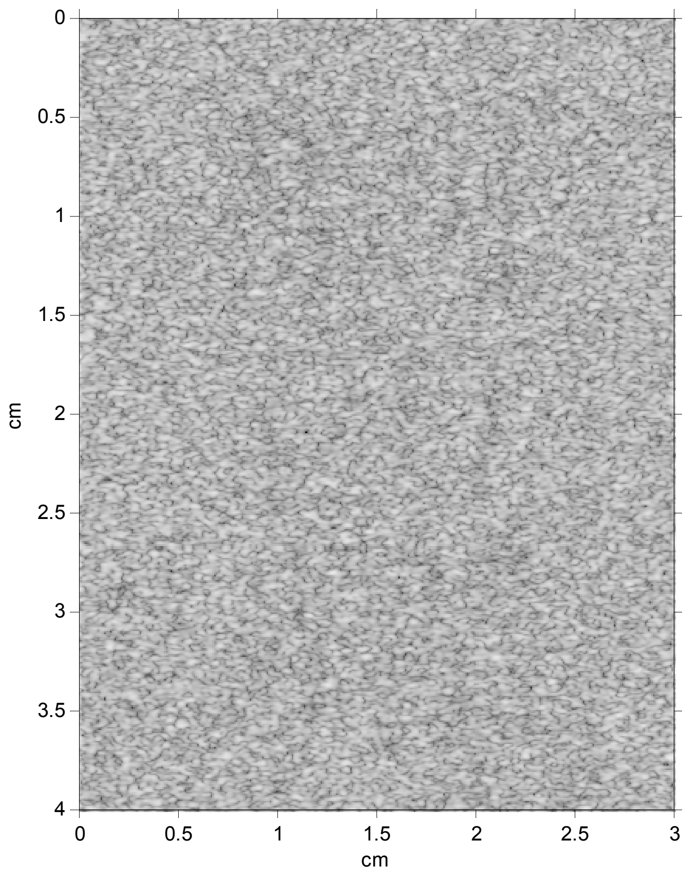
How to improve detection

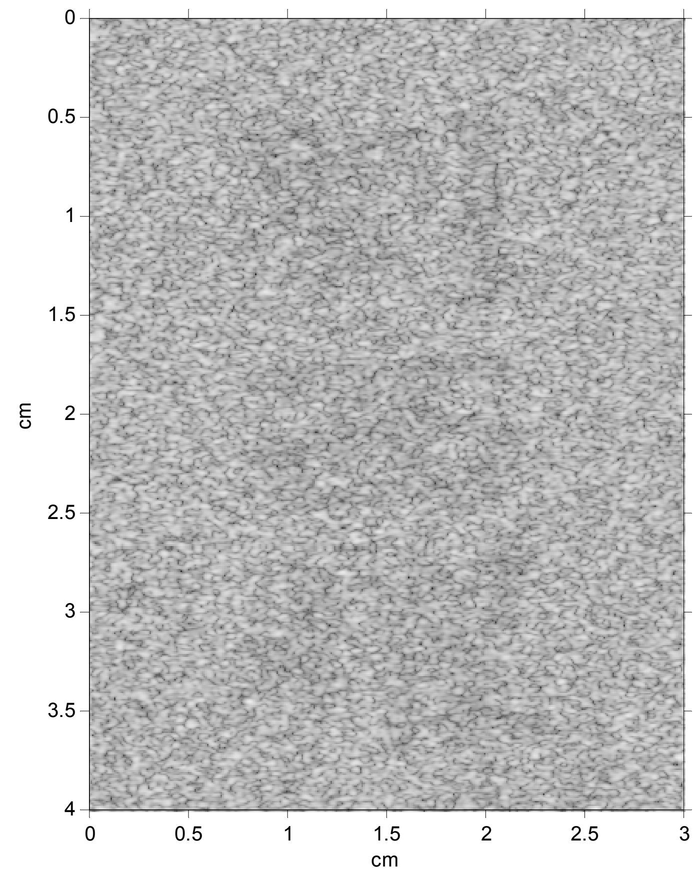
- 1) increase independent samples M
- 2) increase contrast (difference between means of background and target)
  - Somewhat obvious, so we will not discuss this in particular
- 3) reduce variance

Increasing independent samples M

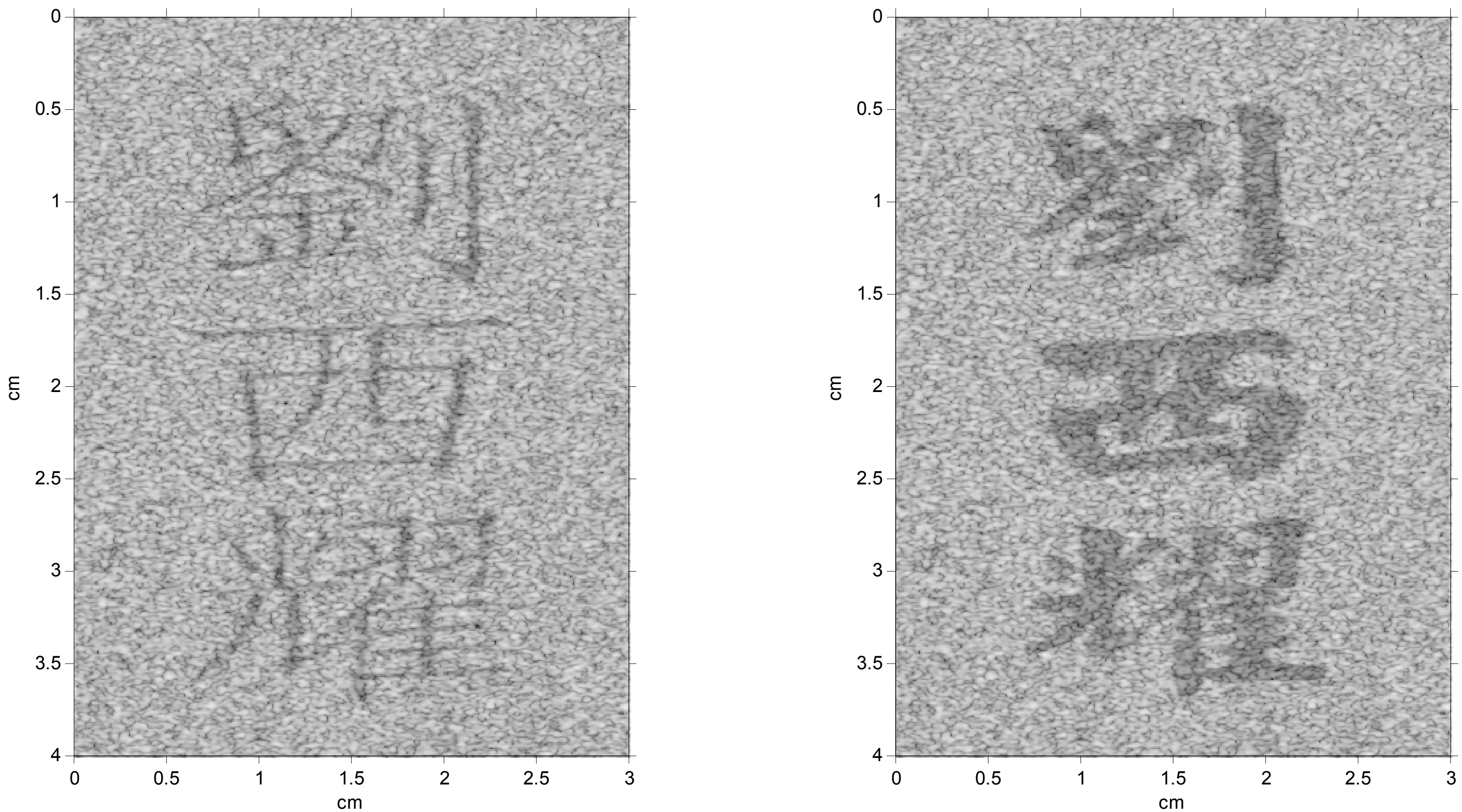
- 1) Can be done by increasing target area
- 2) Can be done by decreasing speckle size

-3 db contrast. Thin vs thick





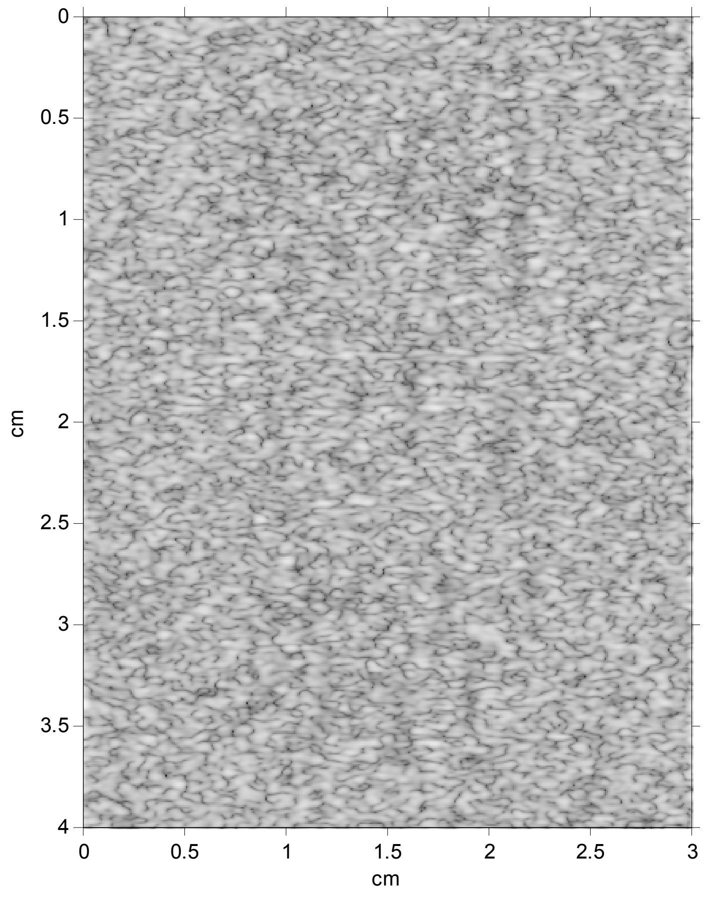
-10 db contrast Thin vs thick



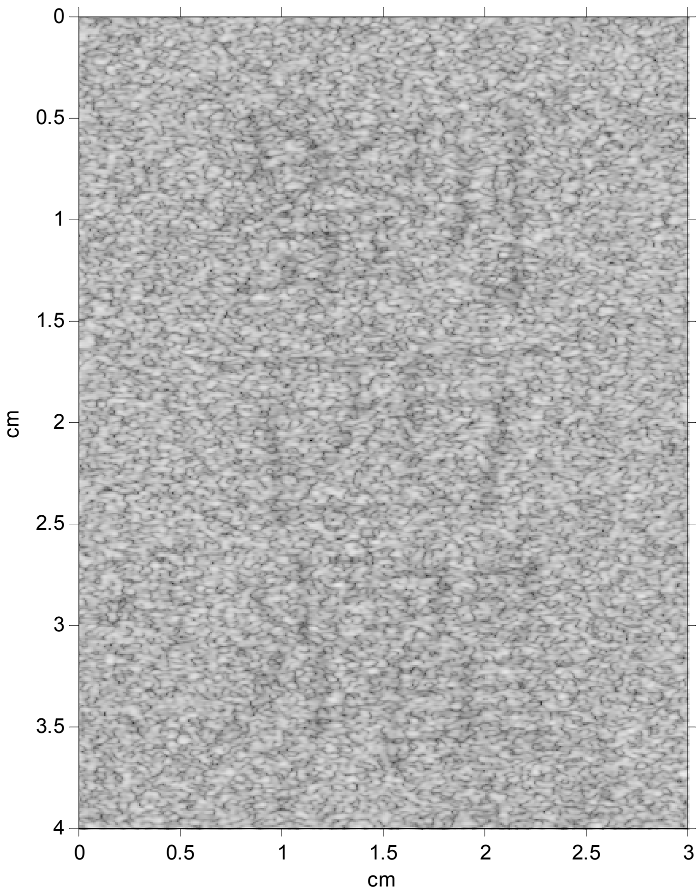
Decreasing speckle size

- In real life, we cannot just make a small cyst larger just so we can see it clearer!
- If target is fixed in size, we can increase the number of independent samples by decreasing speckle size
  - higher frequency
  - higher bandwidth
  - larger aperture

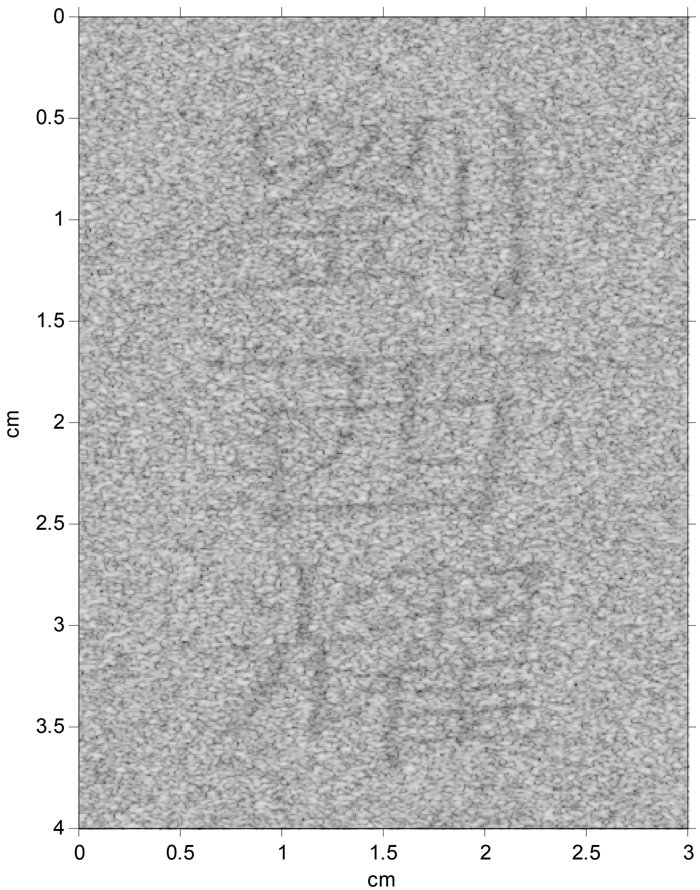
5 MHz, 50% fractional BW



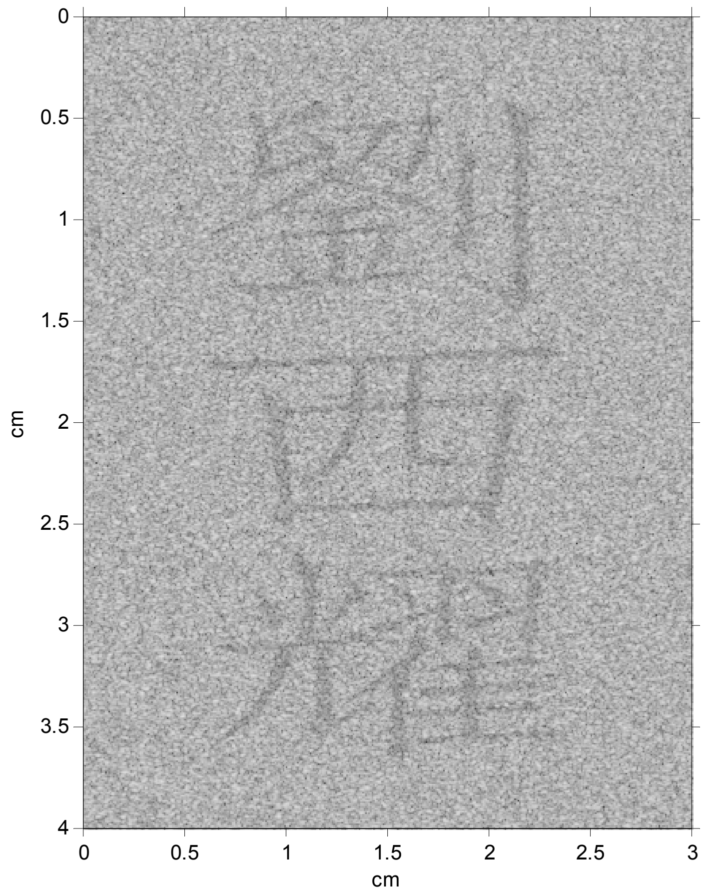
7.5 MHz, 50% fractional BW



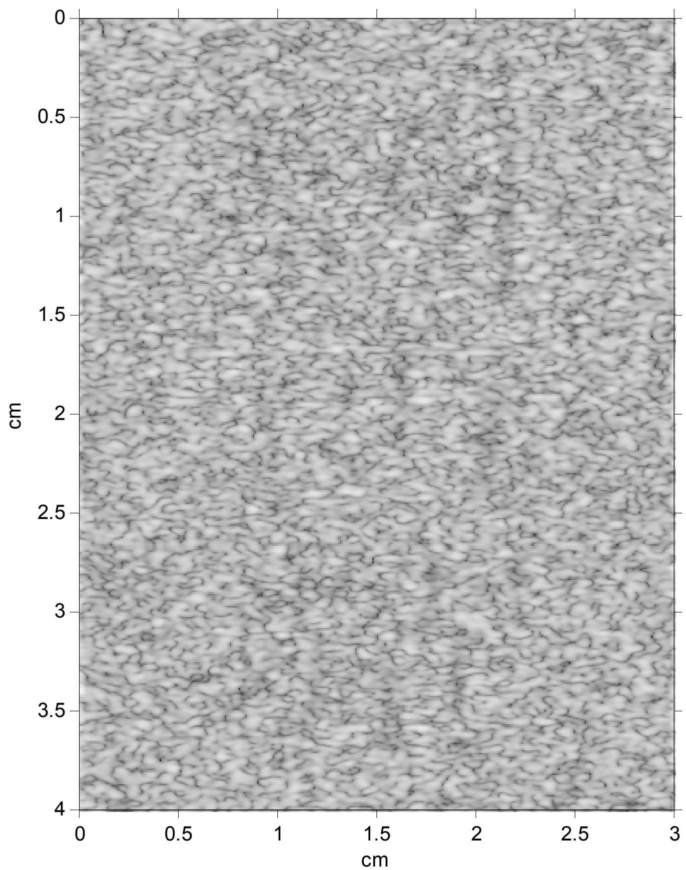
10 MHz, 50% fractional BW



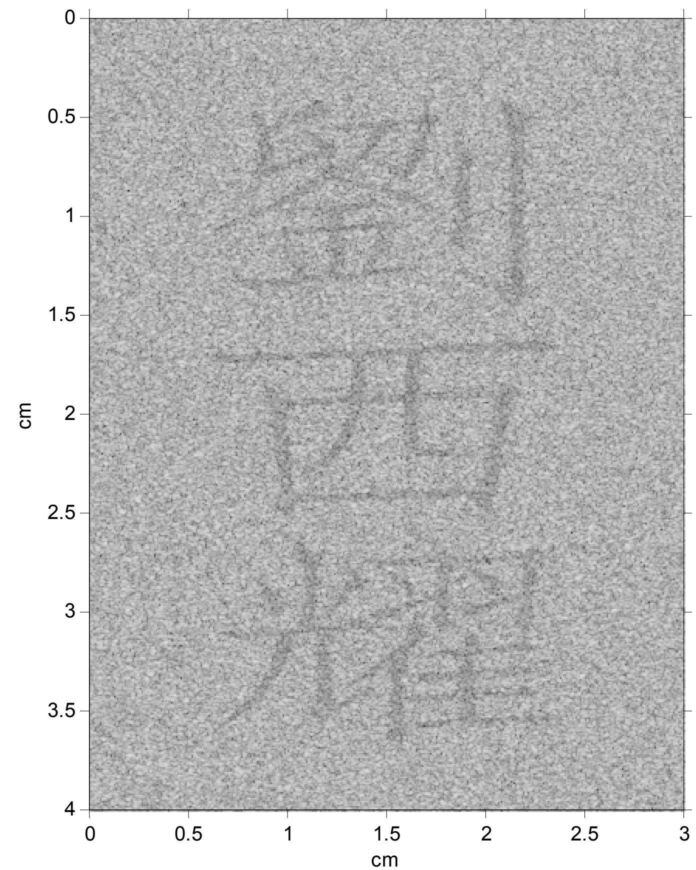
15 MHz, 50% fractional BW



Side by side comparison



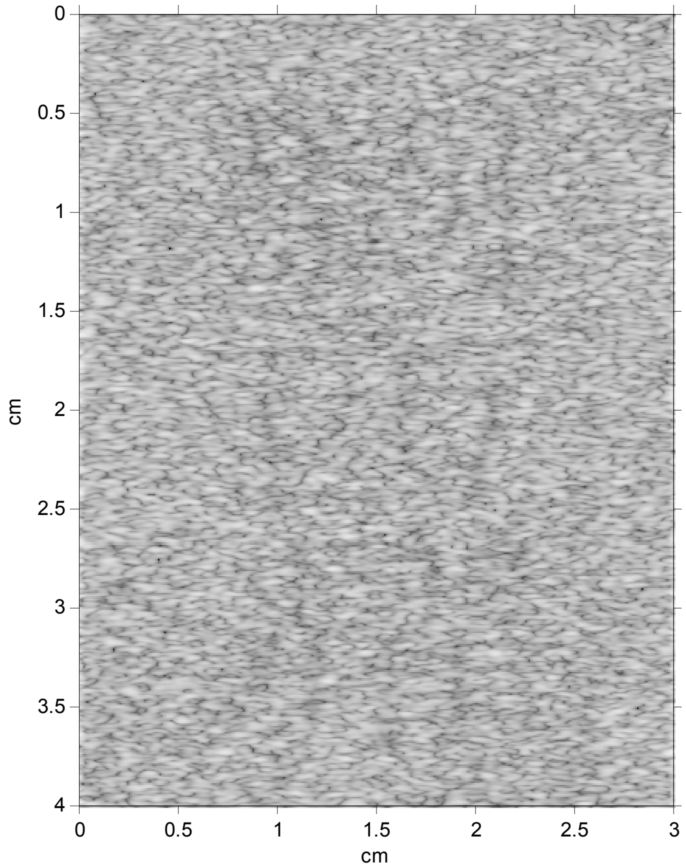
5 MHz, 50% BW



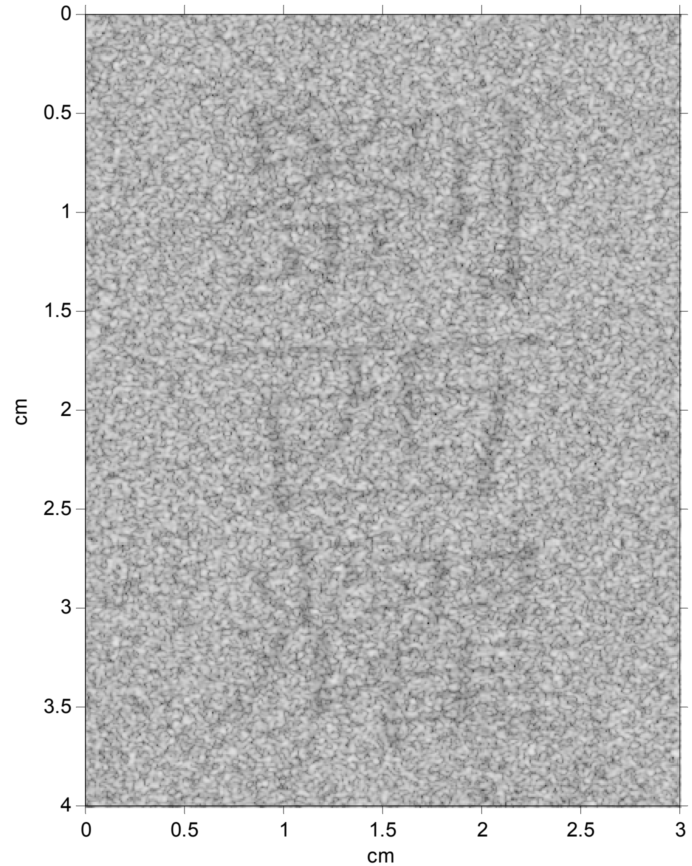
15 MHz, 50% BW

7.5 MHz, 50% BW.

Left represents a 64 channel system with 3.8 cm 128 element linear probe (1.9 cm aperture). Right represents a full 5 cm aperture.



f# = 5/1.9



f# = 1

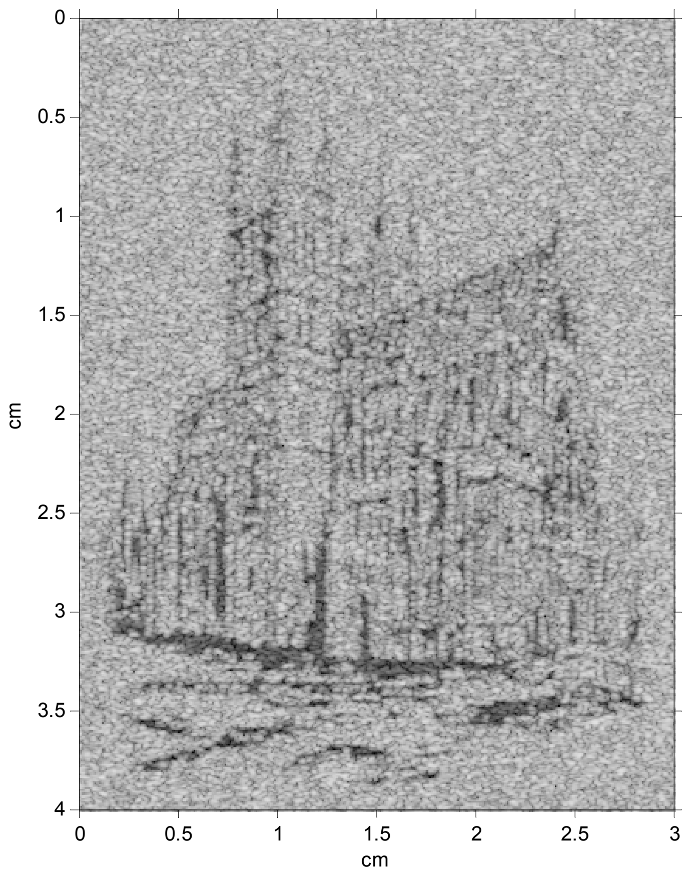
Reduce variance

- Last way to increase detectability is to reduce variance
- For Rayleigh envelope, mean over standard deviation is fixed at 1.91 regardless of frequency, bandwidth or other parameters
- Hence for a fixed brightness, it seems as if variance is fixed

Solution

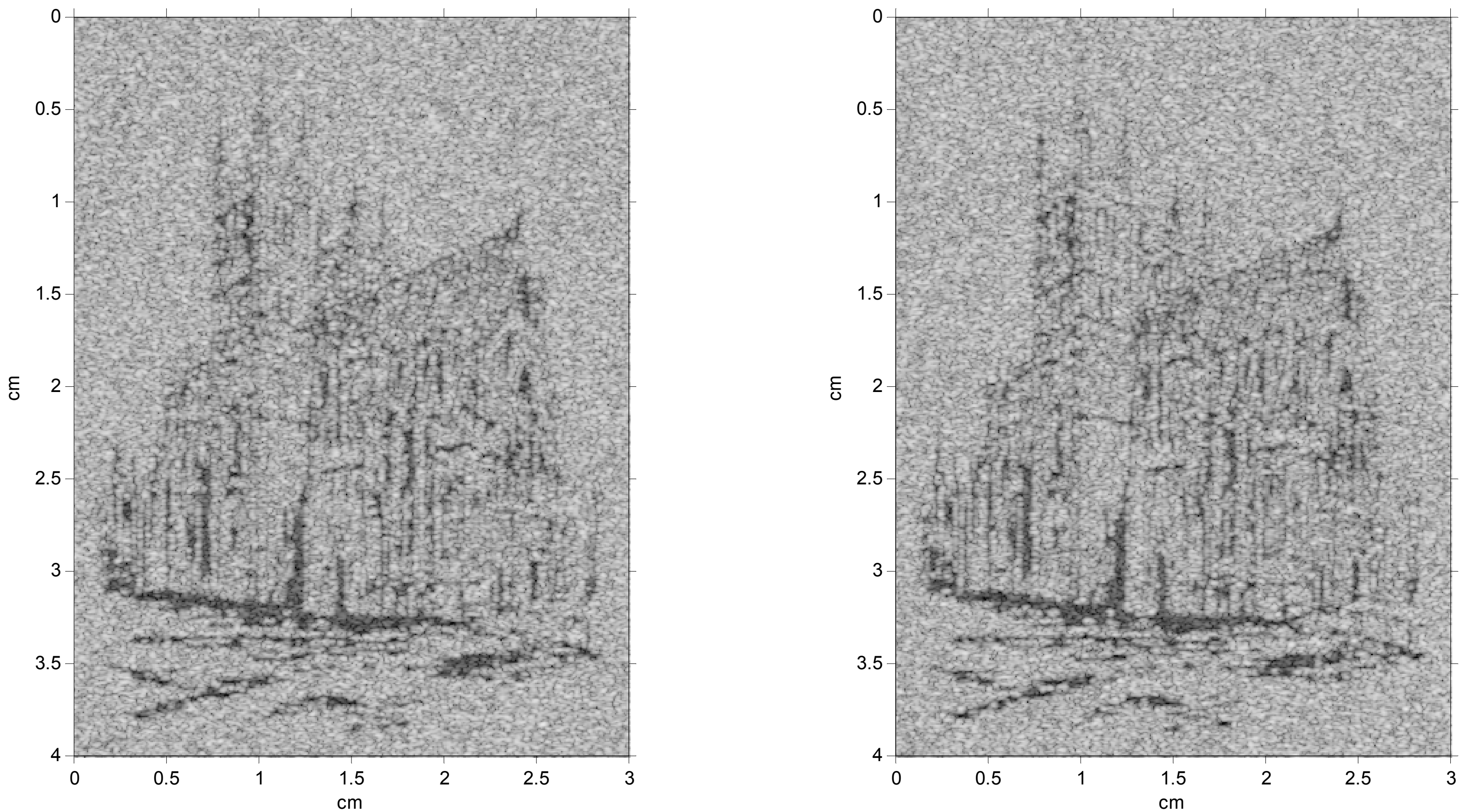
- Speckle reduction methods change the envelope statistics and will lower variance
- We give an example of ideal compounding, which is using independent scatterers to give independent speckle patterns
  - Note that this cannot be done in real life, but in simulation this can be done
- Variance drops by the number of averaged envelope

10 MHz, 50% BW, instance 1 and original picture

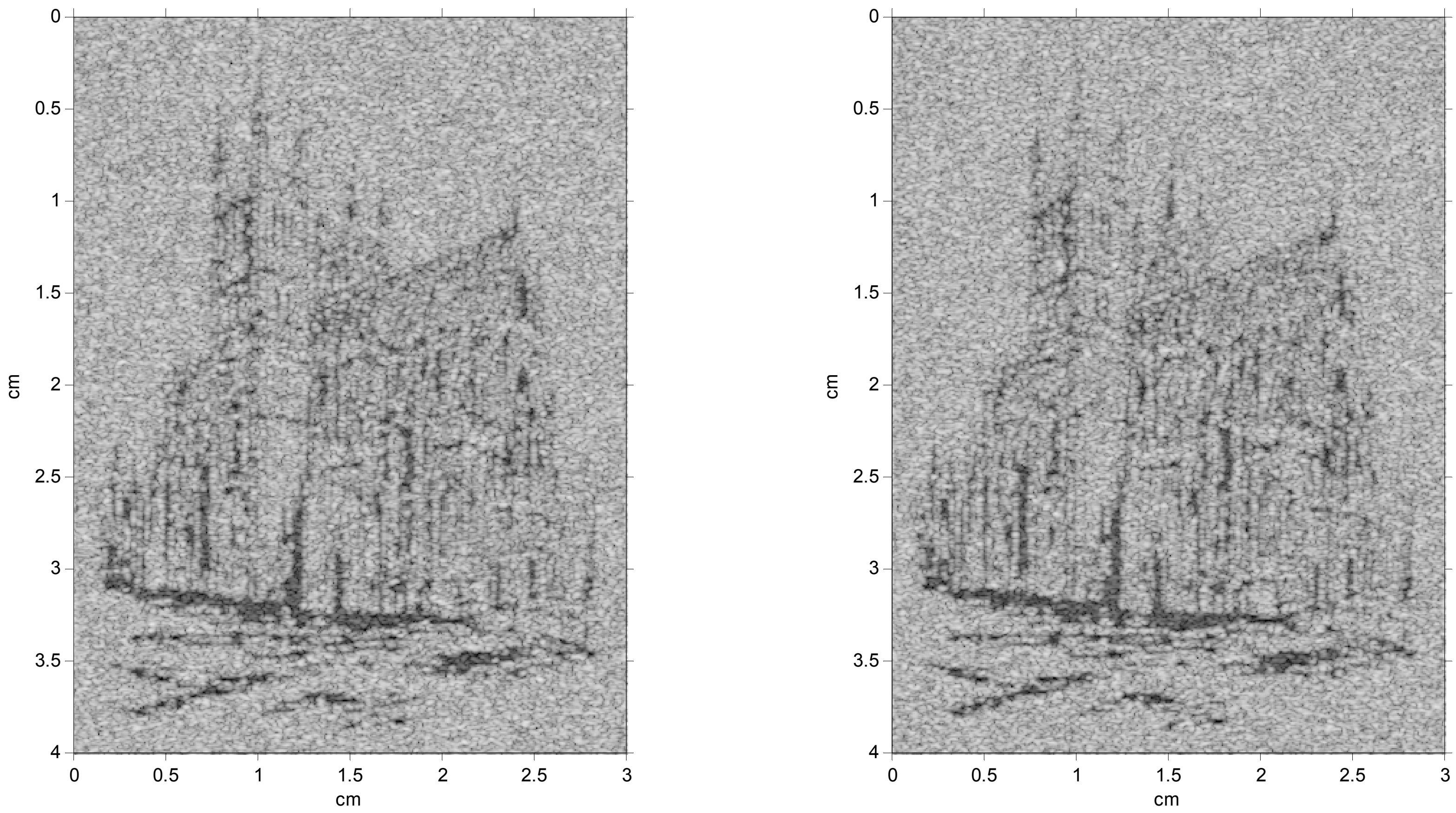


-20 db contrast between target and background

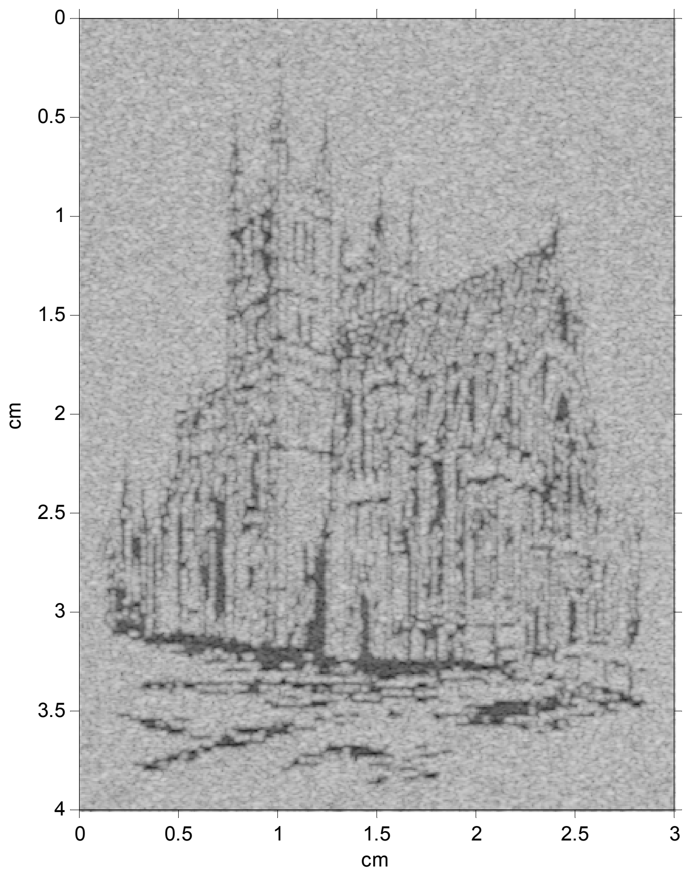
10 MHz, 50% BW, instance 2 and 3



10 MHz, 50% BW, instance 4 and 5



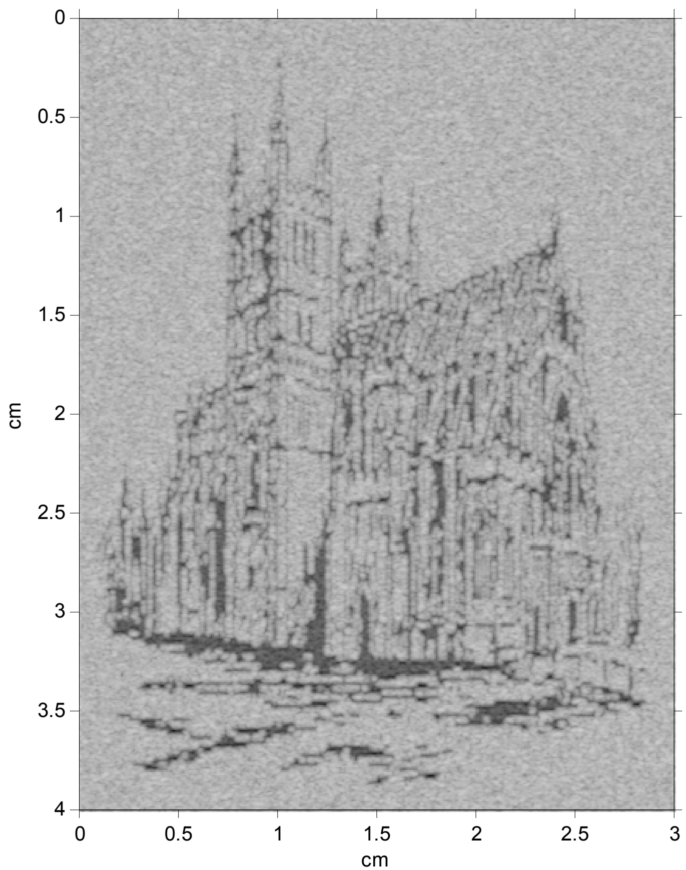
10 MHz, 50% BW, average over 3 instances



Averaged over 3 instances

Original picture

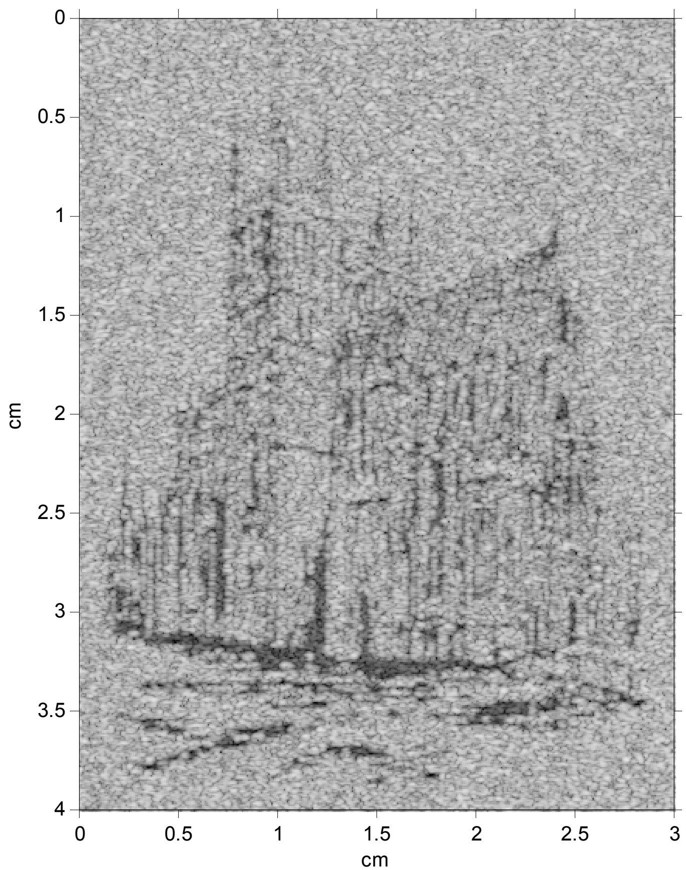
10 MHz, 50% BW, average over 3 instances



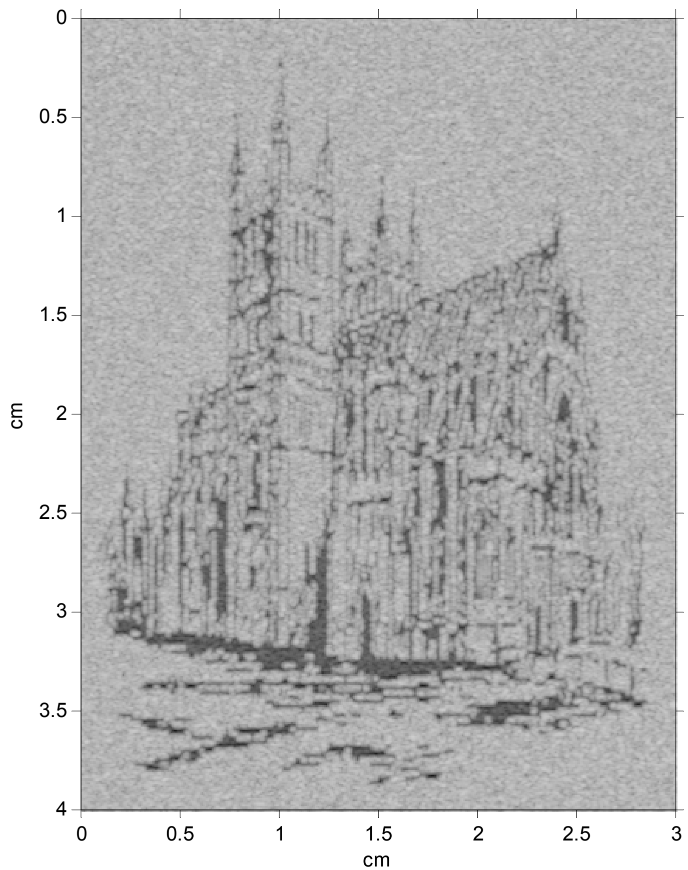
Averaged over 3 instances

Original picture

Side by side comparison



1 instance

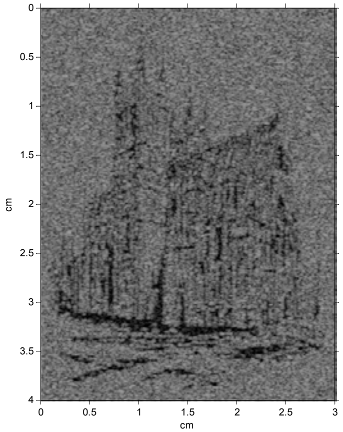


5 instance

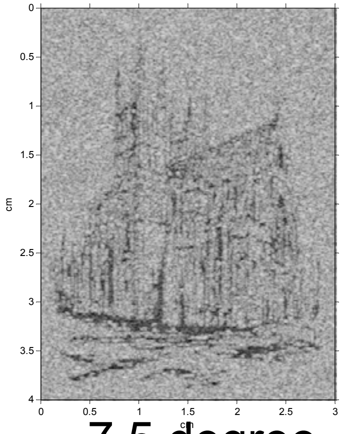
Spatial compounding – a more realistic simulation

- Fix the scatterer field to be identical
- Vary the angle of isonification

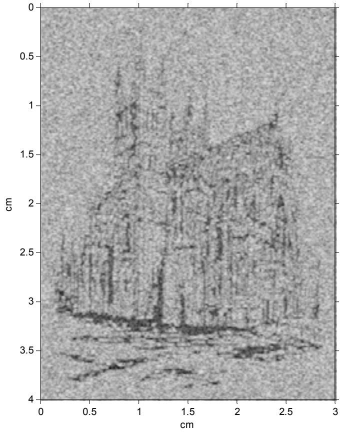
Images



-15 degree

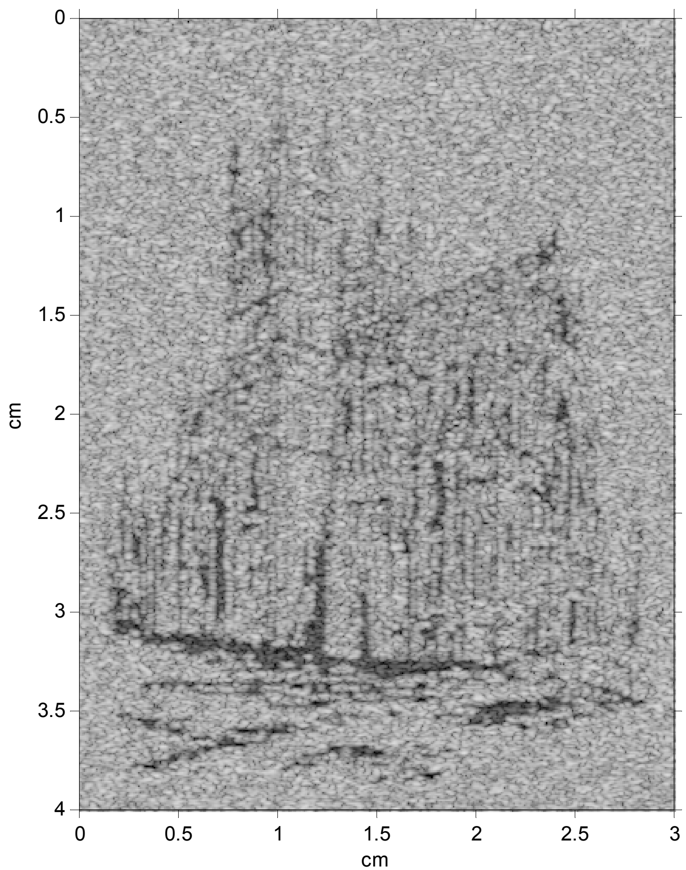


-7.5 degree

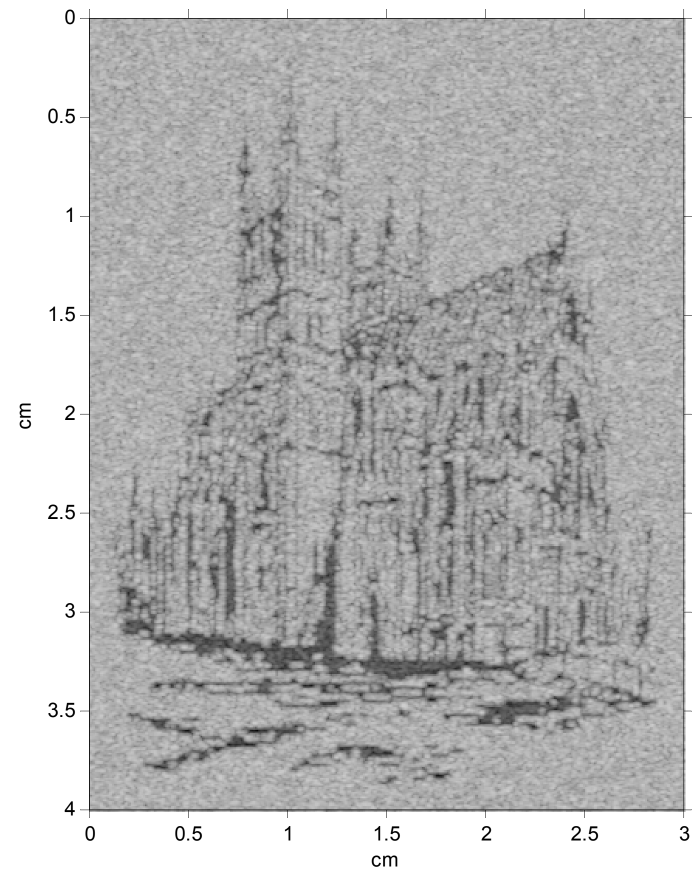


0 degree

Spatial compounding



0 degree



average of -7.5, 0, 7.5 angles

Speckle reduction

- Image processing based methods also will reduce speckle, at the trade off of manipulating images

Conclusion

- The question of if a target is present in the background can be solved using detection theory
  - Decision function is: (sum of squared envelope of target) - (sum of squared envelope of background)
- Better detection occurs with
  - More independent speckle spots of target area
  - Higher contrast between target and background
  - Lower variance of envelope
- All three observations match intuition
  - Simulation allows one to vary many variables and get a feel for what is “detectability”
  - Human observation then matches the theoretical derivation