Test Target Design, Fabrication and Analysis For C-Scan Ultrasonic System Characterization

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Project Goals

- Develop and fabricate thin-film resolution targets suitable for ultrasound C-scan configuration calibration and analysis:
  - Choose an appropriate substrate
  - Find an appropriate scattering pattern

- Develop analysis software for repeatable system characterization

- Perform system characterization using these analysis tools
Background

Physics of ultrasound

Audible Sound
Frequency: 20 Hz - 20 kHz

Ultrasound
Frequency: > 20 kHz

Medical Ultrasound
Frequency: 1 - 20 MHz

Speed of sound in air: 344 m/s
Background

Physics of ultrasound

Acoustic Impedance:
\[ Z = \rho \nu \]

\( \rho \) - physical density
\( \nu \) - velocity of sound

Intensity of Reflection:
\[ R = \left(\frac{Z_1 - Z_2}{Z_1 + Z_2}\right)^2 \]

Axial resolution determined by wavelength
Lateral resolution determined by beam width
Background

Physics of ultrasound

Transducer

Scanner surface

Target

air

Target

Scanner surface

air

Transducer

Target

Scanner surface

air

Transducer

Target

Scanner surface

air

Transducer

Target

Scanner surface

air

Transducer

Target

Scanner surface

air

Transducer

Target

Scanner surface

air

Transducer

Target

Scanner surface

air

Transducer

Target

Scanner surface

air

Transducer
Background

Ultrasound Imaging Modalities

A-Scan

B-Scan

C-Scan

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Background

C-Scan Systems

Time gating

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TEST TARGETS (Phantoms):

- Used for testing and measuring the performance of ultrasonic imaging systems

- Have regions of controlled scattering echogenicity which contain sub-resolvable scatterers

- Reveal the behavior of all the stages in the imaging chain in terms of the MTF and resolution limits

- When considering the analysis of C-scan system, these properties cannot be evaluated with conventional ultrasound test targets
Requires Test Targets

- Involves the fabrication of thin film resolution targets (phantoms)
- Different substrates and scattering patterns will be investigated
- Thin films will be used to obtain quantitative data on image output

- Ultrasound calibration Parylene C film target
- 20µm x 20 µm x 10 µm
- 100X Magnification
Thin films

**SUBSTRATES:**
- **Parylene C**
  - Allows for high-resolution scattering target creation through silicon etching techniques
  - Film has similar echogenic properties to human tissue
- **Plastic Films**
  - Maliable, inexpensive
  - Thick plastic films allow for a variety of scattering pattern creation
- **Metal Target**
  - Provides high wave reflection
  - Allows for precise scattering pattern etching

**SCATTERERS:**
- A variety of patterns were etched onto the different substrates in order to find the best possible scatterers
  - Line pairs
  - Radial patterns
  - Etc.
In the beginning...

- Project started with B-scan configuration in mind
  - Parylene C film, 30 μm in thickness, was grown and pattern - etched using lithography
  - Lines were made of checkerboard pattern, 20 x 20 x 10 μm
C scan of initial Parylene C film

Scanline across image of film

Scanline Across Image of Film

0 50 100 150 200 250 300 350 400 450 500

0 50 100 150 200 250 300

Pixel Location

Pixel Value

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Contrast is low due to axial resolution of the system

Axial resolution is defined as:

$$\frac{\lambda \cdot \text{cycles}}{2} \approx 100 \mu m$$

MTF from system output using the preliminary film
Polyethylene Terephthalate

- Configuration requires thicker substrate and deeper etched pattern than Parylene C etching allows.

- P.E.T. film substrate was chosen.
  - Test patterns could be laser-etched into the film.
Image Output
Metal Test Target

Stainless steel resolution target

1 cm squares
Initial Results

Information obtained from test targets

Thin Film:

24 Squares

Each Square:
0.08 cm

1.92 cm
Test Target

Image:

Height:
375 pixels

\[
\text{Height} = \frac{1.92 \text{ cm}}{375 \text{ pixels}} = 0.512 \, \mu\text{m per pixel}
\]

No radial distortions

1: 343 pixels
2: 344 pixels
3: 344.6 pixels
Acquisition and Analysis
Windowed edge spread function (ESF)

Line spread function (LSF)
(also derivative of edge spread function)

MTF (Fourier Transform of LSF)

MTF comparisons

Derivative

Fourier Transform
Line Target Analysis

Scanline

Fourier Transform

Line Spread Function

Amplitude (pixel value)

Position (pixel location)

0  100  200  300  400  500

0  50  100  150  200  250

Modulation Transfer Function of Frequency

Amplitude

0  0.5  1.0

0  500  1000  1500  2000  2500  3000  3500  4000  4500  5000

Spatial Frequency (Cycles/m)
Line Target Analysis

Deformities caused by laser etching process

Raking light experiment (Image Microstructure Lab, RIT CIS)

Light source

Computer

Digital microscope

Target

Light from right minus light from left
Line Target Analysis

Deformities caused by laser etching process
(Confocal Microscope Lab, RIT Department of Biology)

Confocal Microscope Scan  Digital reconstruction and projection

QuickTime™ and a decompressor are needed to see this picture.
Line Target Analysis

Other deformities

Confocal Microscope Scan

Digital reconstruction and projection

QuickTime™ and a decompressor are needed to see this picture.
Metal Test Target

Other deformities

Left raking

Right raking

Left minus right
Edge Target Analysis

- Derivative
- Fourier Transform
- Scanline
Edge Target Analysis

Varying coupling agents

- Water
- Soap
- Oil
- Ultrasound Gel

MTF Using Different Coupling Agents

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Edge Target Analysis

Varying amounts of coupling agent

Low

Medium

High

MTF Using Diff. Amounts of Coupl. Agents
Edge Target Analysis

Scanlines across edges at different angles

MTFs Across Edges at Different Angles

- Horizontal
- Vertical
- Oblique
Results

MTF From System
Image Output:

MTF From System
Transducer, Only:
Results

Modulation Transfer Function of Frequency

MTF From Output

MTF From Bare Transducer

Spatial Frequency (Cycles/m)

Amplitude

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Conclusions

• Adequate thin-film test targets were created for the C-Scan system by using air-to-target edge analysis and laser-etched PET scattering patterns
• System characterization was performed to provide information on the signal degradation within the system, as seen by comparing MTF of image output to the MTF calculated using the stand-alone system transducer
• The PET thin films themselves were analyzed to provide information concerning deformities produced by the laser-etching process that infer possible image degradation
• Effects produced by the quantity and type of coupling agent were analyzed. The type used has little effect while the amount used has a large effect
• This information has been used to add to a complete protocol for C-scan target design and testing and for C-scan system characterization
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