# An Introduction to TG-142 Imaging QA Using Standard Imaging Products

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Standard Imaging, Inc.

# Goals

- Understand the nature and intent of TG-142 imaging metrics,
- Introduce some imaging phantoms used by PIPSpro,
- Understand how our software works,
- Develop an intuitive appreciation of the mathematics.

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# TG-142, Table VI – Imaging QA

**Daily**

**Planar kV and MV (EPID) imaging**

~~Collision interlocks~~
~~Positioning/repositioning~~
~~Imaging and treatment coordinate coincidence (single gantry angle)~~

**Cone-beam CT (kV and MV)**

~~Collision interlocks~~
~~Imaging and treatment coordinate coincidence~~
~~Positioning/repositioning~~

**Monthly**

**Planar MV imaging (EPID)**

~~Imaging and treatment coordinate coincidence (four cardinal angles)~~
Scaling[b]
Spatial resolution
Contrast
Uniformity and noise

**Planar kV imaging[d]**

~~Imaging and treatment coordinate coincidence (four cardinal angles)~~
Scaling
Spatial resolution
Contrast
Uniformity and noise

**Cone-beam CT (kV and MV)**

Geometric distortion
Spatial resolution
Contrast
HU constancy
Uniformity and noise

**Annual**

**Planar MV imaging (EPID)**

~~Full range of travel SDD~~
~~Imaging dose[e]~~

**Planar kV imaging**

~~Beam quality/energy~~
~~Imaging dose~~

**Cone-beam CT (kV and MV)**

~~Imaging dose~~

- Mechanicals
- Positioning
- Imaging Dose

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# PIPSpro - Imager QA Metrics

| **Metric** | **QC-3, QCkV-1** | **Catphan 503, 504, 600*** |
|---|---|---|
| Geometric Distortion – Volumetric | | X |
| Uniformity | X | X |
| Noise | X | X |
| Contrast | X | X |
| Spatial Resolution | X | X |
| Hounsfield Unit Constancy | | X |
| Low-Contrast Visibility** | | X |
| Low-Contrast Detectability*** | | X |

** The Phantom Laboratory*

*** Elekta Acceptance Test*

**** Not available with 503…missing the 515.*

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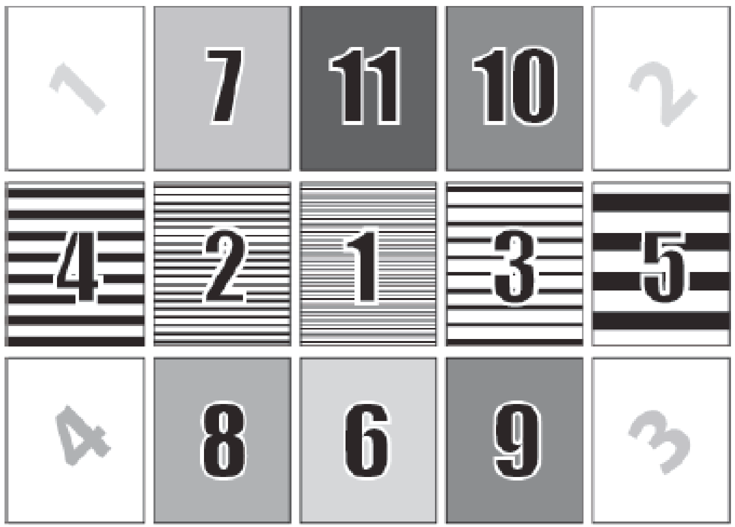
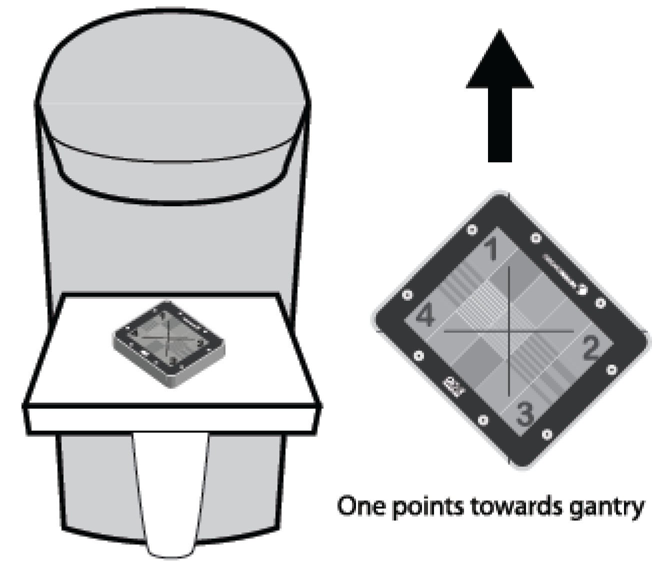
# QC-3 Phantom



One points towards gantry

- Noise
- Contrast
- Spatial resolution
- Uniformity*

| | QC-3 | |
|---|---|---|
| Region | Bar resolution lp/mm | Bar thickness mm |
| 1 | 0.76 * | 15 mm lead |
| 2 | 0.45 * | 15 mm lead |
| 3 | 0.25 * | 15 mm lead |
| 4 | 0.20 * | 15 mm lead |
| 5 | 0.10 * | 15 mm lead |
| 6 | | 15 mm PVC |
| 7 | | 15 mm Aluminum |
| 8 | | 5 mm lead |
| 9 | | 7.5 mm lead |
| 10 | | 7.5 mm lead |
| 11 | | 15 mm lead |

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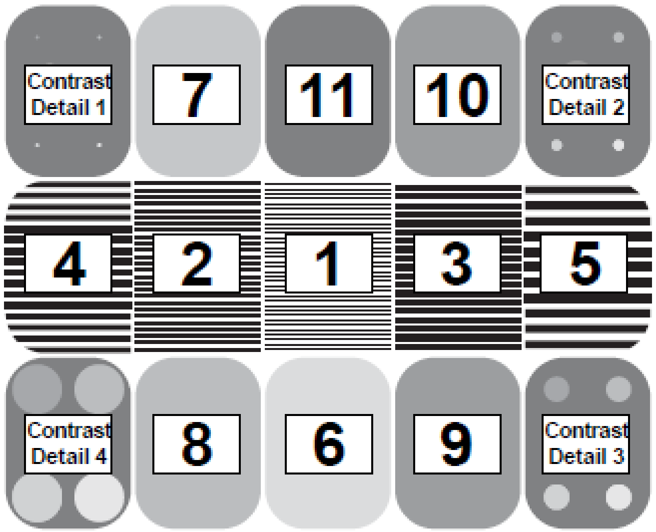
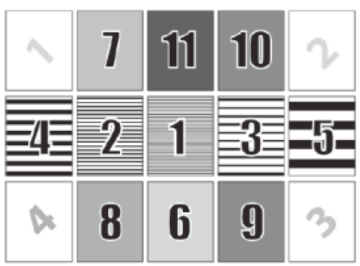
# QCkV-1 Phantom




| Region | QCkV-1 |
|---|---|
| | Bar resolution lp/mm (Bar thickness inches) |
| 1 | 2.46 (0.008) |
| 2 | 2.00 (0.010) |
| 3 | 1.50 (0.013) |
| 4 | 0.98 (0.020) |
| 5 | 0.66 (0.030) |
| | Transmission Rate at 80 kV |
| 6 | 10% |
| 7 | 20% |
| 8 | 30% |
| 9 | 40% |
| 10 | 40% |
| 11 | 50% |

*Essentially identical to QC-3, but for kV and adds contrast detail regions.*

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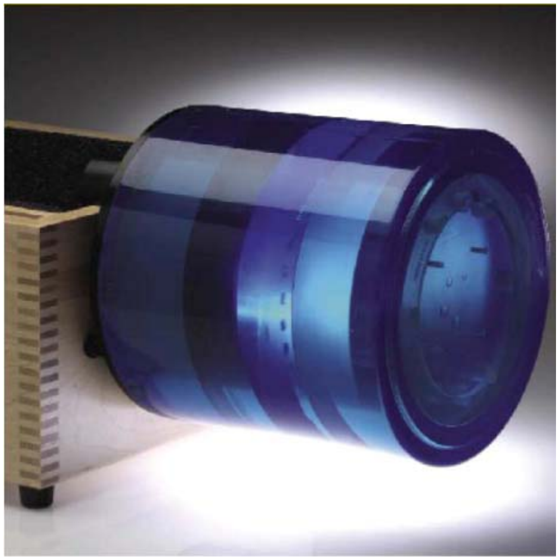
# Catphan Phantom Family



The following diagrams were taken from Catphan manuals, which are all available online.

| Catphan | M1 | M2 | M3 | M4 | M5 | |
|---|---|---|---|---|---|---|
| 503 | 404 | 528 | 486 | | | Elekta |
| 504 | 528 | 404 | 515 | 486-2 | | Varian |
| 600 | 404 | 591 | 528 | 515 | 486 | Siemens |

*Module Inserts*

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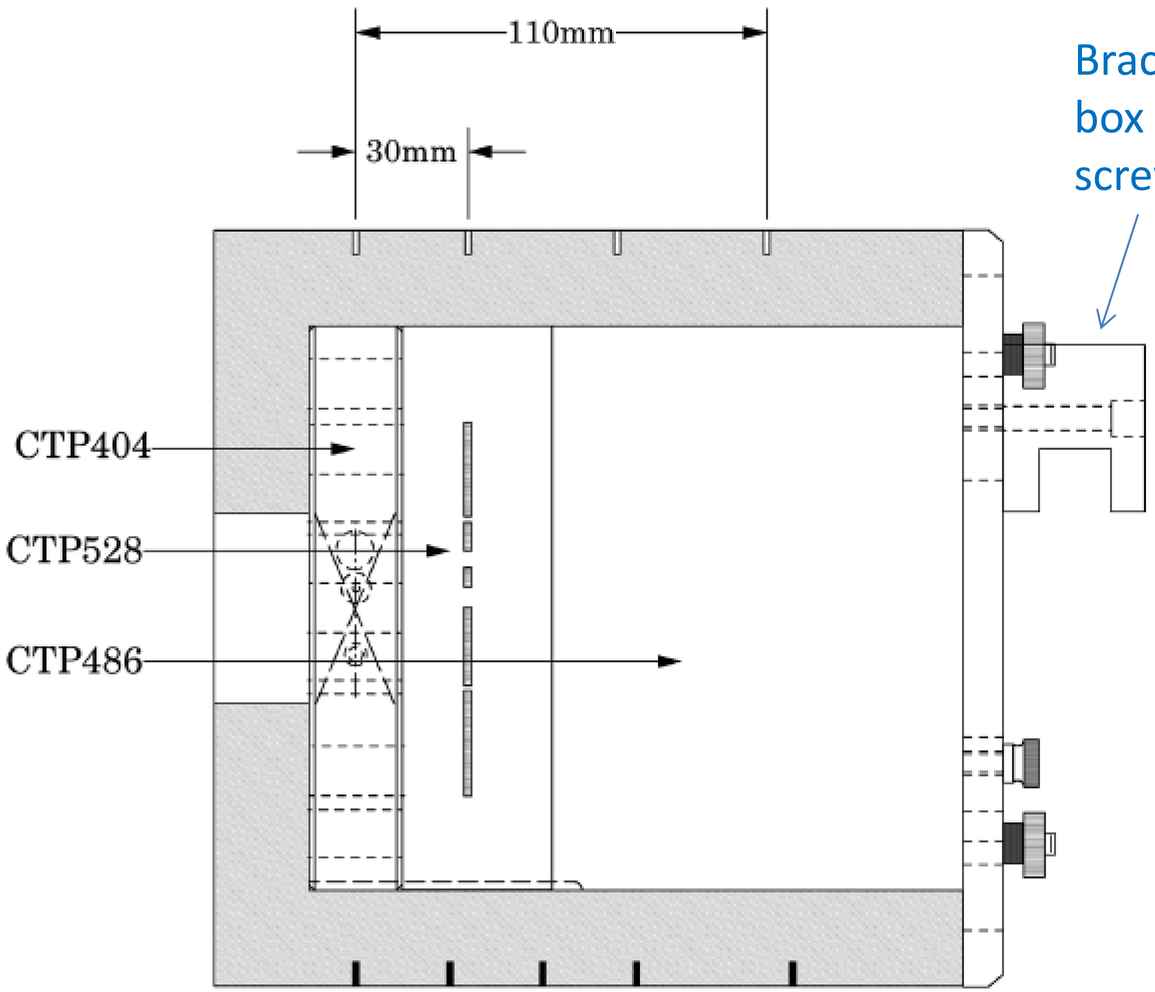
# Catphan 503




Brackets to attach to box and adjustment screws.

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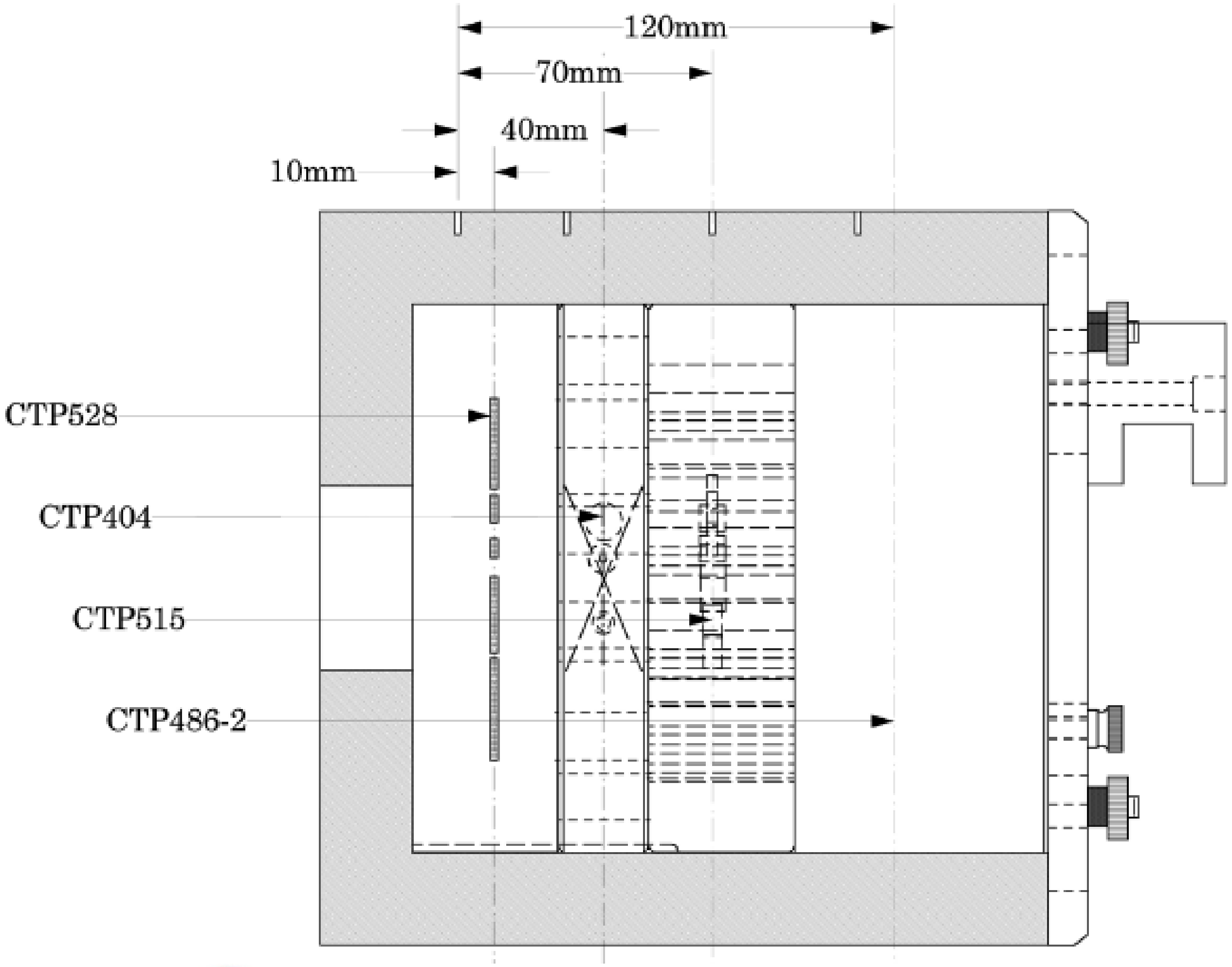
# Catphan 504

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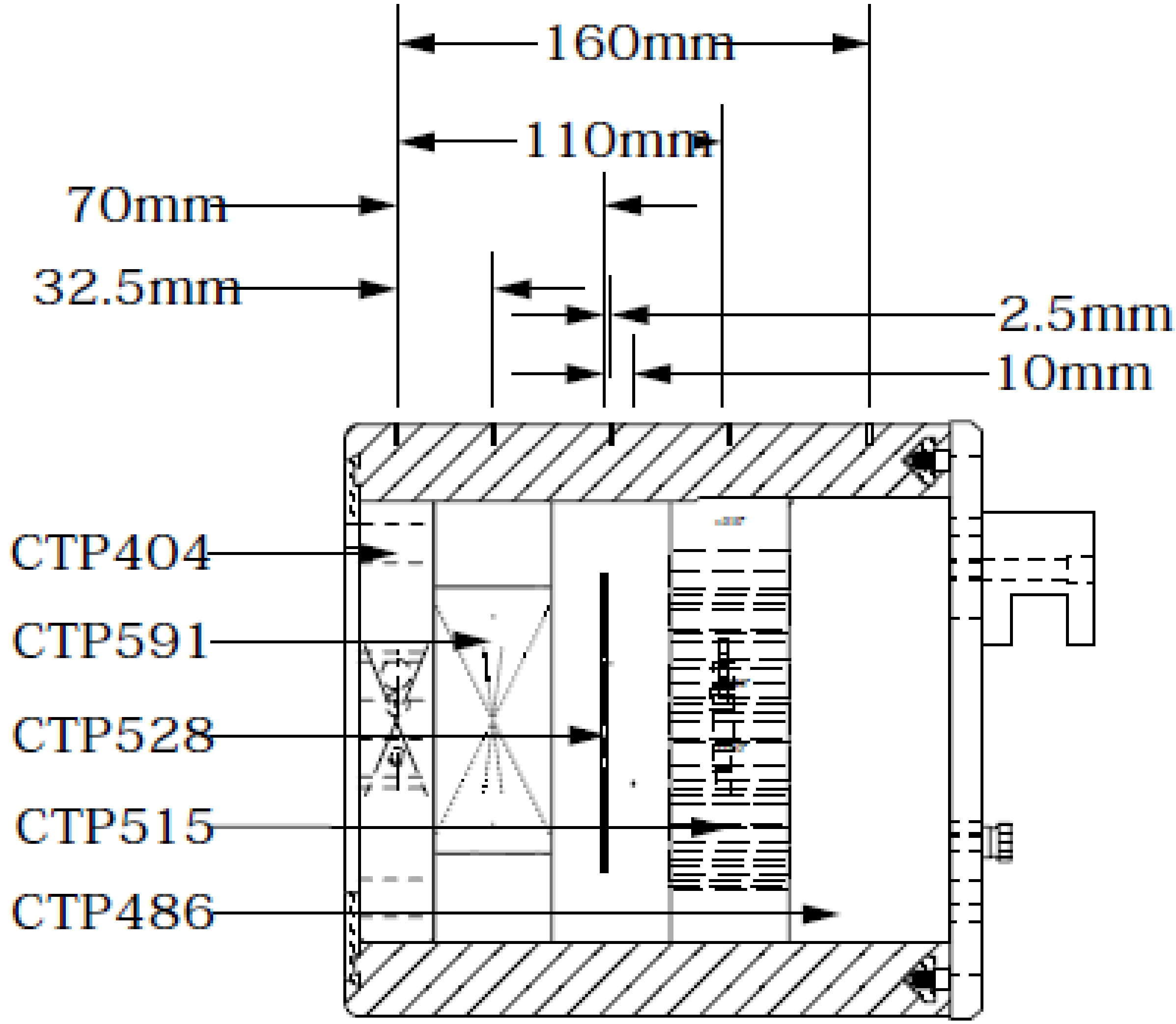
# Catphan 600

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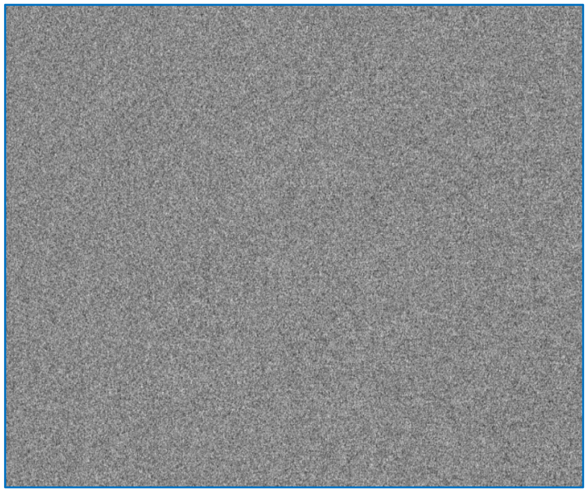
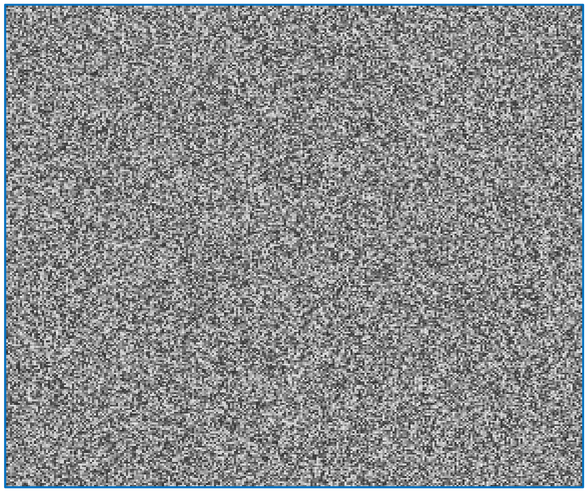
*What distinguishes the phantoms are the analysis modules and their placement….*

# Noise

$$NSI = \sigma_{flood} = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(x_i - \mu)^2}$$

- Noise is calculated as the standard deviation of the pixel values of a region in an image.
- Noise represents <u>random</u> detector signal fluctuations.
- Noise is assumed to be "stationary".

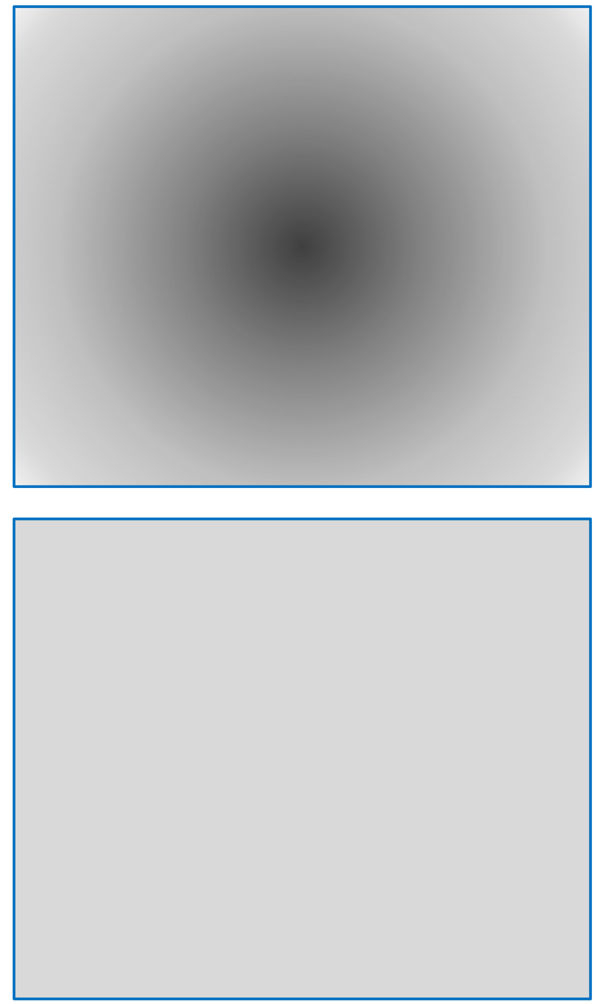




*Which image is noisier?*

# Uniformity

- (Non)uniformity represents <u>systematic</u> detector signal fluctuations.
- (Non)uniformity can be removed (improved) through system calibration.



*Which image is more uniform?*

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503, 504, 600

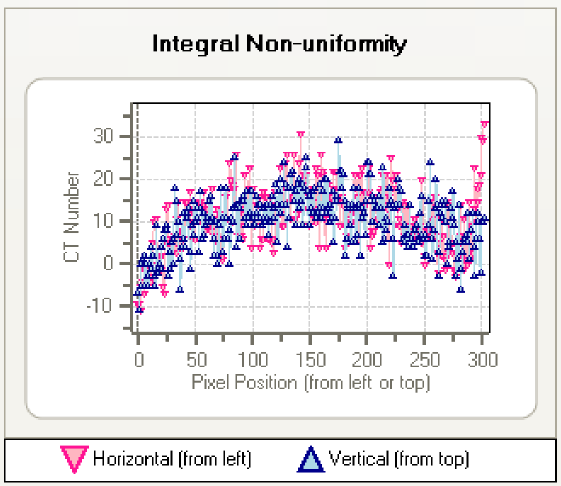
# CTP 486 - Image Uniformity Module

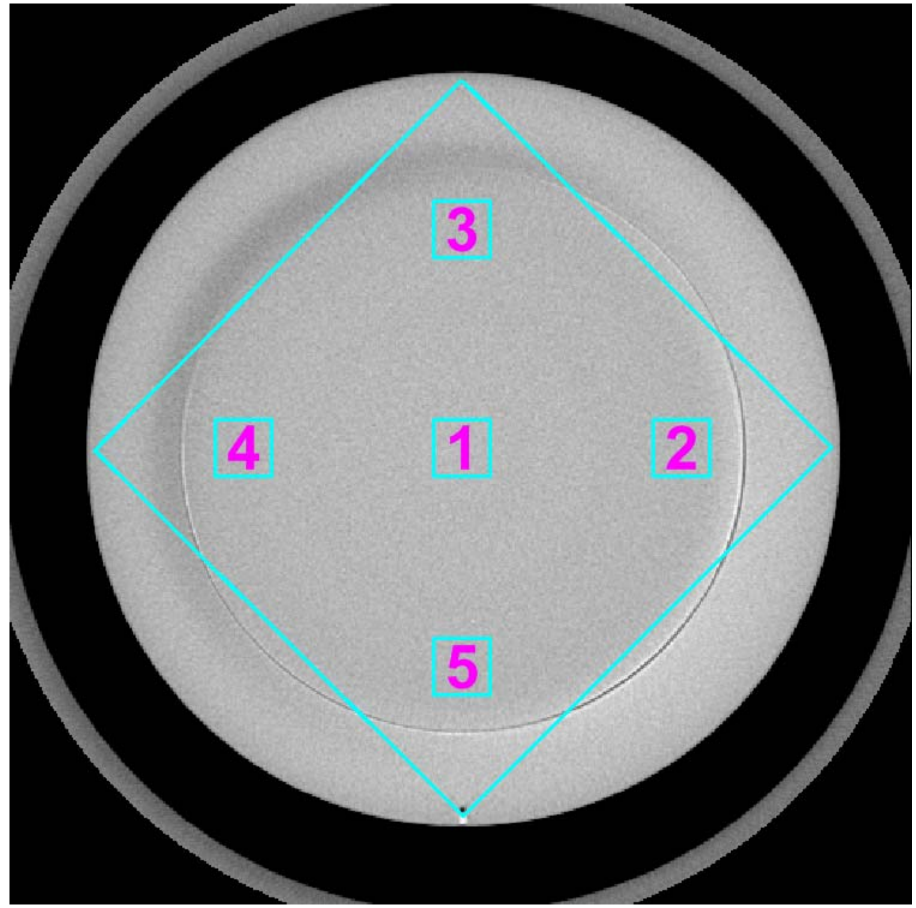
### Uniformity and Noise

| Hounsfield Numbers | | |
|---|---|---|
| ROI | Mean | Sigma |
| 1 | 15.708 | 10.138 |
| 2 | 6.870 | 9.770 |
| 3 | 4.918 | 10.455 |
| 4 | 4.928 | 10.217 |
| 5 | 6.890 | 9.891 |

The mean value of each region of interest (ROI) is used to quantify uniformity. The standard deviation (Sigma) is used to quantify noise

| | Vertical | Horizontal |
|---|---|---|
| Integral non-uniformity | 2.000 | 2.222 |

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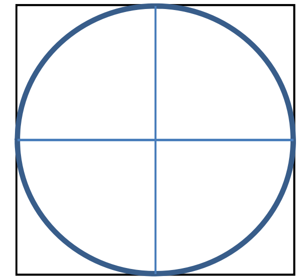
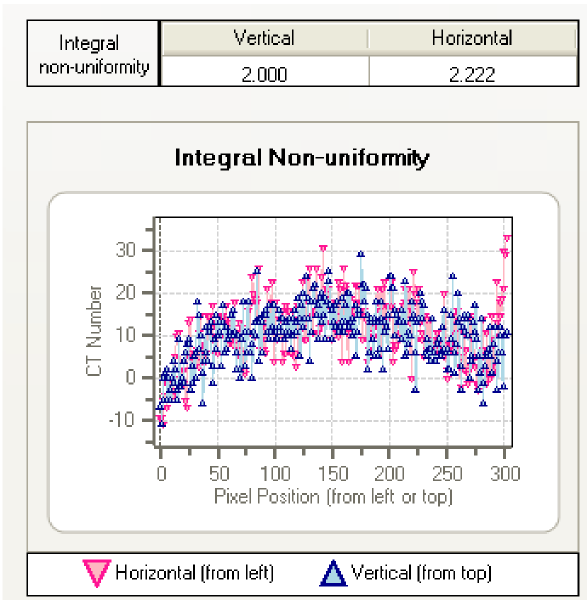
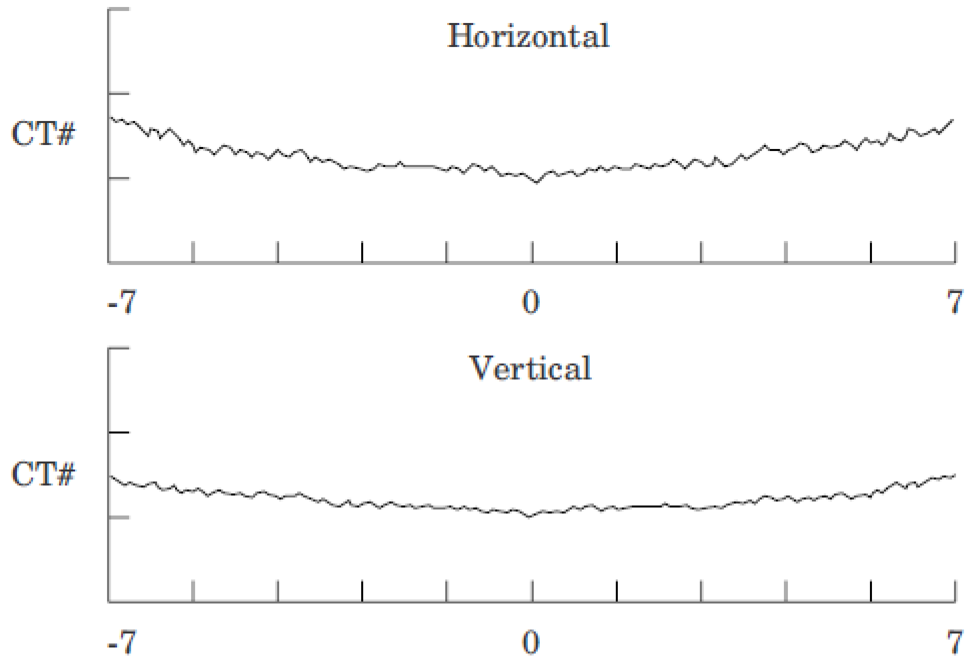
# Integral Non-Uniformity






$$\text{Integral Non-Uniformity} = \frac{\text{CTmax} - \text{CTmin}}{\text{CTmax} + \text{CTmin}}$$

- PIPS shows CT#'s plotted on the same graph.
- Note that CBCT images tend to be more noisy than CT images.

*"Cupping" or "capping" of the CT number may indicate the need for recalibration.*

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# A Basic Equation

$$\textit{Integral Non-Uniformity} = \frac{CTmax - CTmin}{CTmax + CTmin}$$

*Same equation as for beam flatness.*

$$\frac{Max - Min}{Max + Min} = \frac{\frac{Max - Min}{2}}{\frac{Max + Min}{2}} = \frac{Maximum\ Difference\ from\ "Midrange"}{"Midrange"}$$

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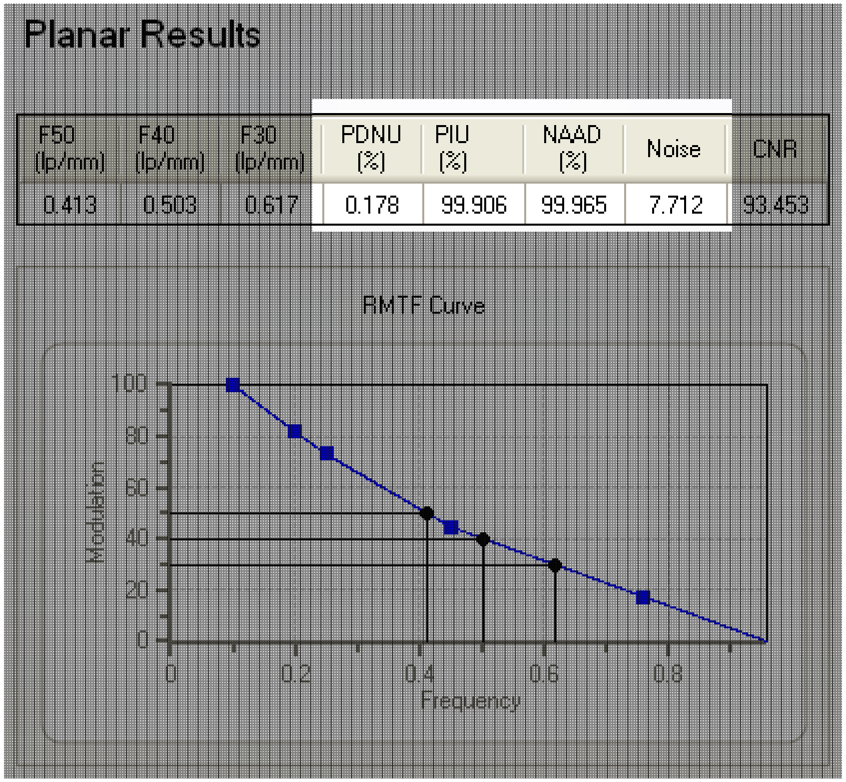
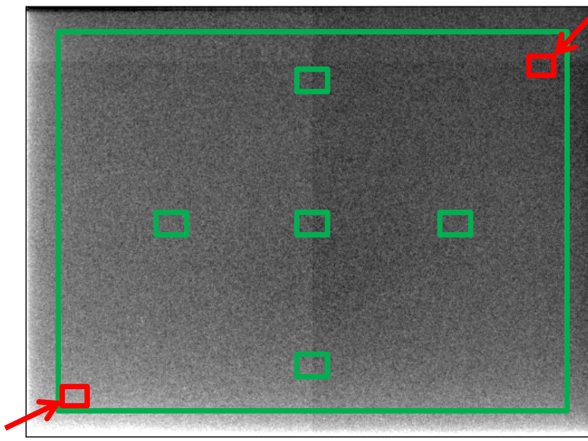
# Single Image – Uniformity and Noise




$$PIU = \left(1 - \frac{\overline{SROI}_{max} - \overline{SROI}_{min}}{\overline{SROI}_{max} + \overline{SROI}_{min}}\right) x100$$




A Percent Integral Uniformity value of 100% *theoretically* means that there is no variability within the useful field of view.

$$\sigma_{overall} = \frac{\sigma_{\Delta 1} + \sigma_{\Delta 2} + \sigma_{\Delta 3} + \sigma_{\Delta 4} + \sigma_{\Delta 5}}{5}$$

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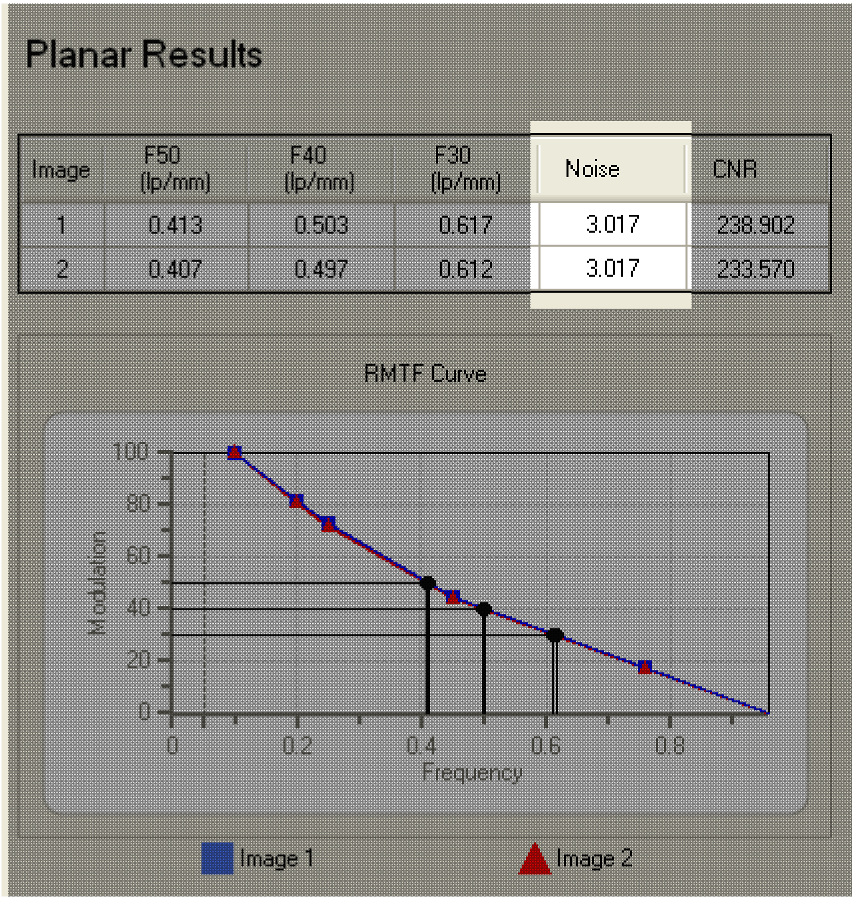
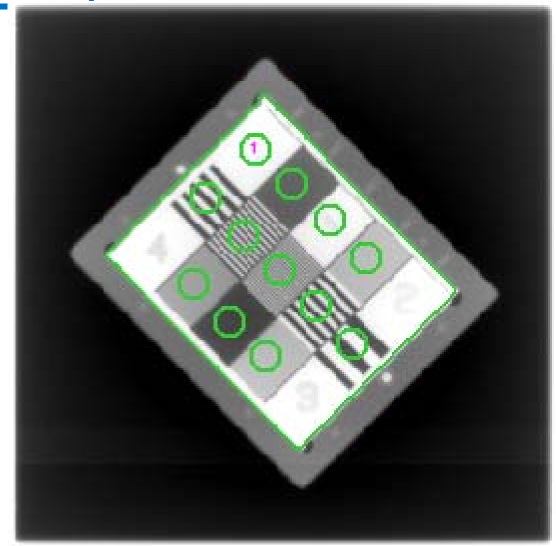
# Dual Image – Noise Only

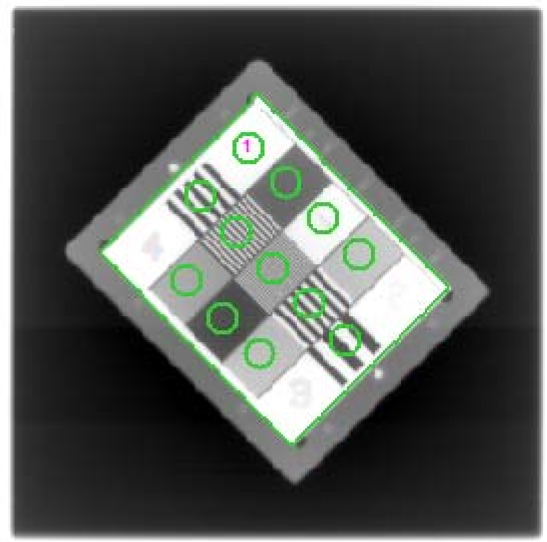


Planar Results

| Image | F50 (lp/mm) | F40 (lp/mm) | F30 (lp/mm) | Noise | CNR |
|---|---|---|---|---|---|
| 1 | 0.413 | 0.503 | 0.617 | 3.017 | 238.902 |
| 2 | 0.407 | 0.497 | 0.612 | 3.017 | 233.570 |







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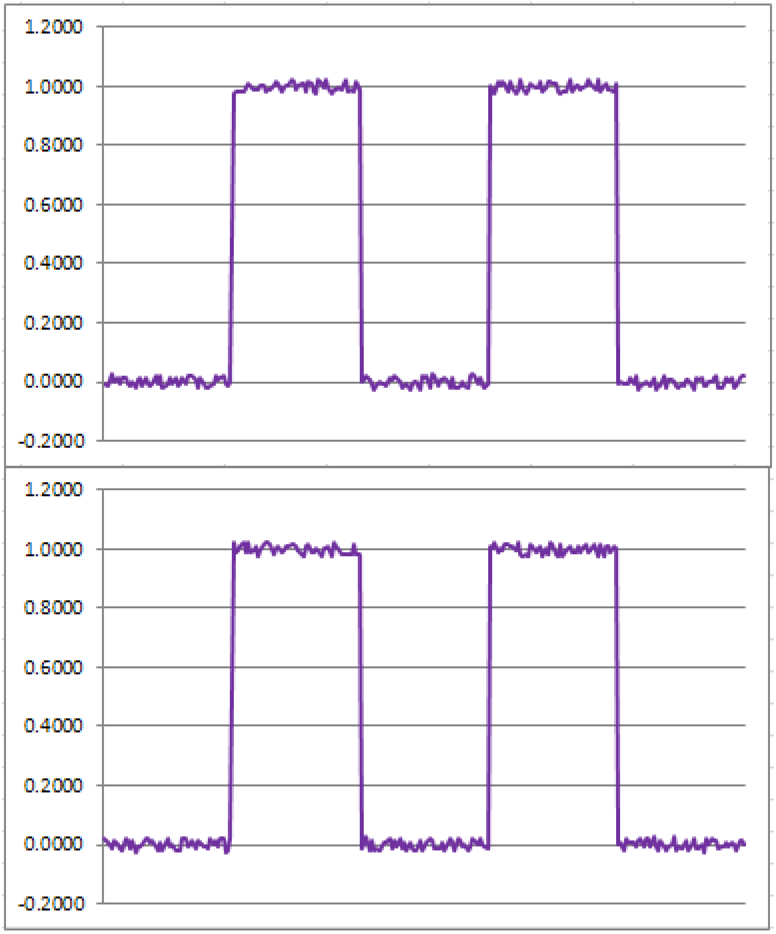
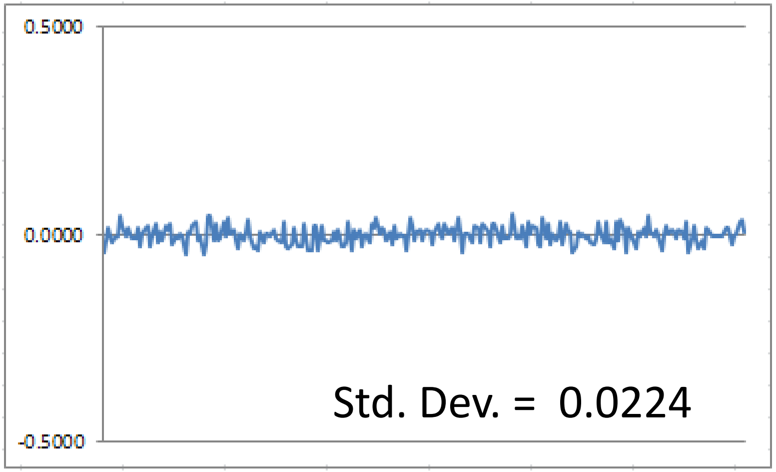
Rajapakshe, Luchka, and Shalev: Quality control test for electronic portal imaging devices - 1996

# Noise (Dual Image)

$$NDI = \sigma_{\Delta} = \sqrt{\frac{1}{2(N-1)} \sum_{i=1}^{N} (x_i - \mu)^2}$$




Subtracting images lets us estimate noise in the region that we are analyzing.

$$\frac{1}{\sqrt{2}} * 0.0224 = 0.0158$$

*~4% error*

$$\frac{0.0146 + 0.0156}{2} = 0.0151$$

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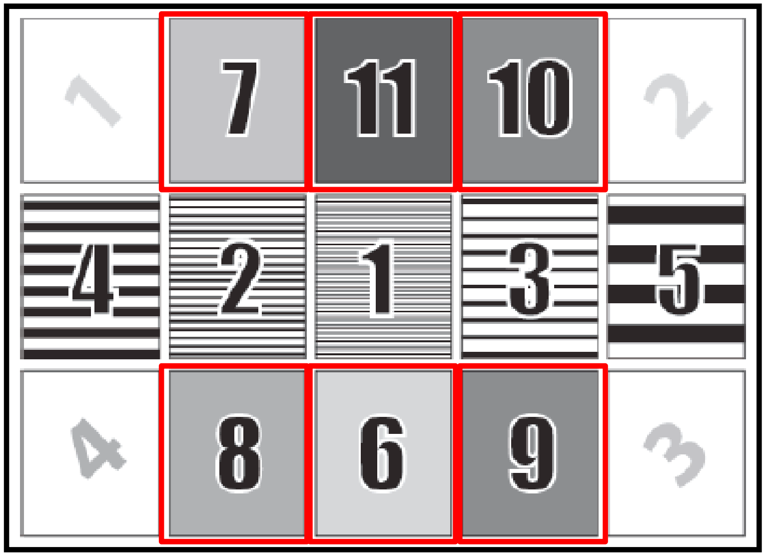
*Assumption: The "images" are the same, the noise is different.*

# PIPSpro - Noise




| | QC-3 | |
|---|---|---|
| Region | Bar resolution lp/mm | Bar thickness mm |
| 1 | 0.76 * | 15 mm lead |
| 2 | 0.45 * | 15 mm lead |
| 3 | 0.25 * | 15 mm lead |
| 4 | 0.20 * | 15 mm lead |
| 5 | 0.10 * | 15 mm lead |
| 6 | | 15 mm PVC |
| 7 | | 15 mm Aluminum |
| 8 | | 5 mm lead |
| 9 | | 7.5 mm lead |
| 10 | | 7.5 mm lead |
| 11 | | 15 mm lead |

$$\sigma_{overall} = \frac{1}{\sqrt{2}} * \frac{\sigma_{\Delta 6} + \sigma_{\Delta 7} + \sigma_{\Delta 8} + \sigma_{\Delta 9} + \sigma_{\Delta 10} + \sigma_{\Delta 11}}{6}$$

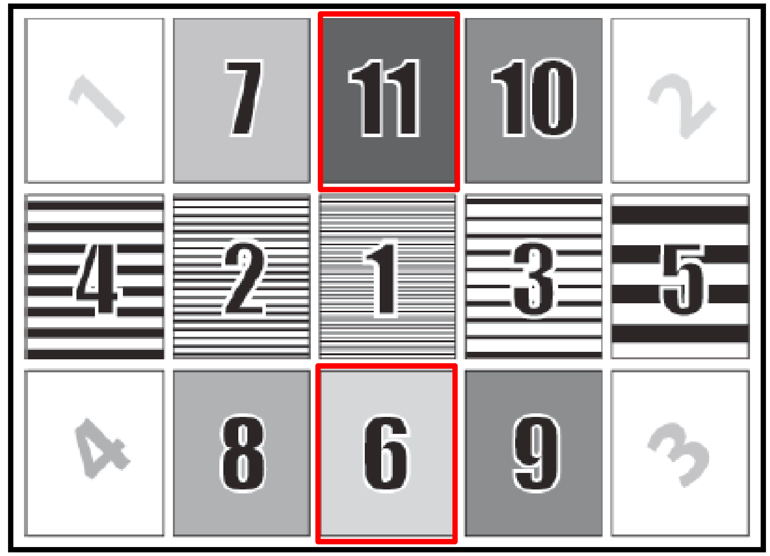
# PIPSpro - Contrast to Noise Ratio

$$CNR = \frac{|\mu_{light} - \mu_{dark}|}{\sigma_{dark}}$$

$\mu_{light}$ Mean of the pixel values in the "lightest" region of an image

$\mu_{dark}$ Mean of the pixel values in the "darkest" region of an image

$\sigma_{dark}$ Standard deviation of the pixel values in the "darkest" region of an image




| | QC-3 | |
|---|---|---|
| Region | Bar resolution lp/mm | Bar thickness mm |
| 1 | 0.76 * | 15 mm lead |
| 2 | 0.45 * | 15 mm lead |
| 3 | 0.25 * | 15 mm lead |
| 4 | 0.20 * | 15 mm lead |
| 5 | 0.10 * | 15 mm lead |
| 6 | | 15 mm PVC |
| 7 | | 15 mm Aluminum |
| 8 | | 5 mm lead |
| 9 | | 7.5 mm lead |
| 10 | | 7.5 mm lead |
| 11 | | 15 mm lead |

$$CNR = \frac{|\mu_{11} - \mu_{6}|}{\sigma_{11}}$$

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# Modulation Transfer Function (MTF)

- The MTF shows the frequency response of the imaging system.
- Higher frequencies are required for greater resolution.
- Thicker screens have better absorption properties but exhibit poorer spatial resolution (lower dose, increased scatter).
- Film (by itself) has far better spatial resolution than that of intensifying screens.

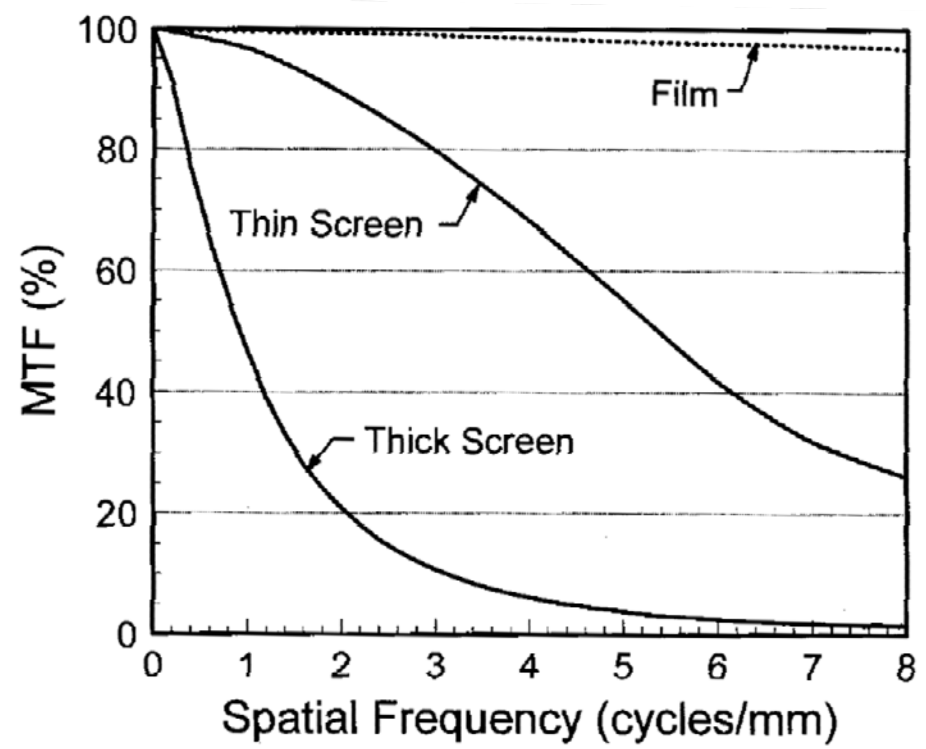


FIGURE 6-8, Bushberg, The Essential Physics of Medical Imaging, 2nd Ed.

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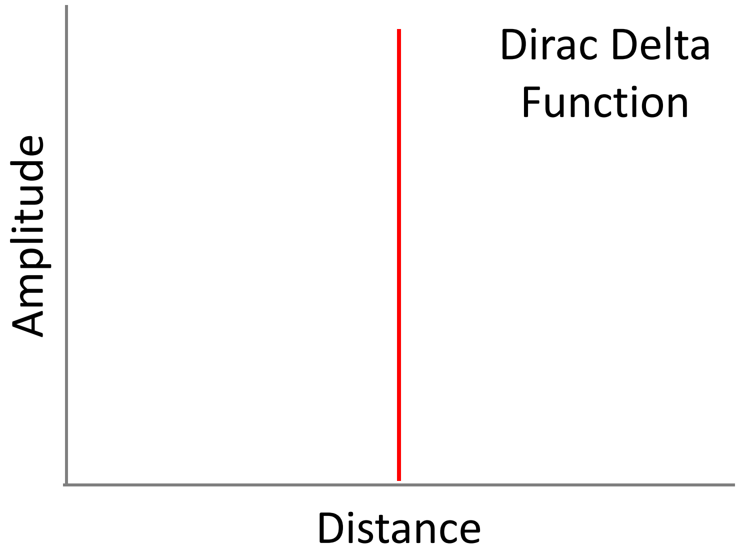
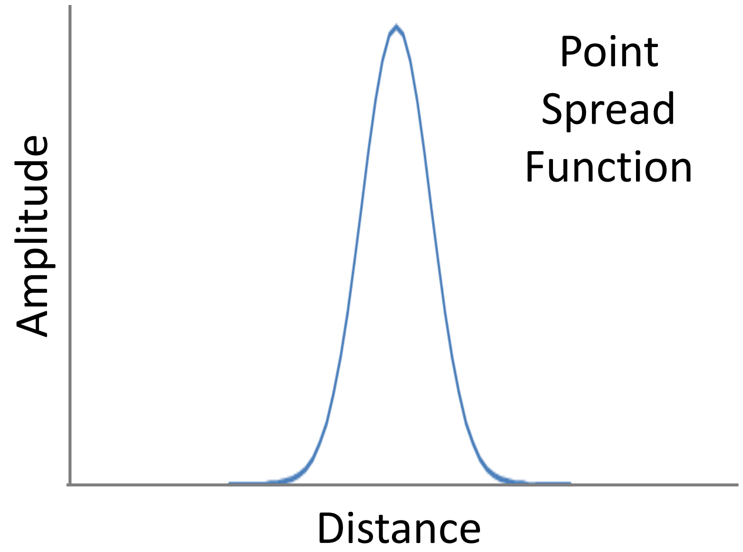
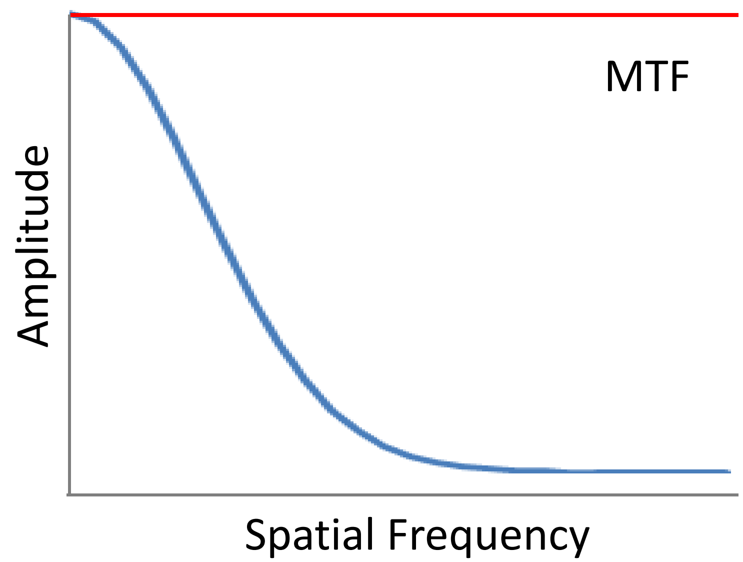
# What I learned to pass my boards.




"The MTF is the magnitude of the Fourier transform of the point or line spread function— the response of an imaging system to an infinitesimally small point or line of light."

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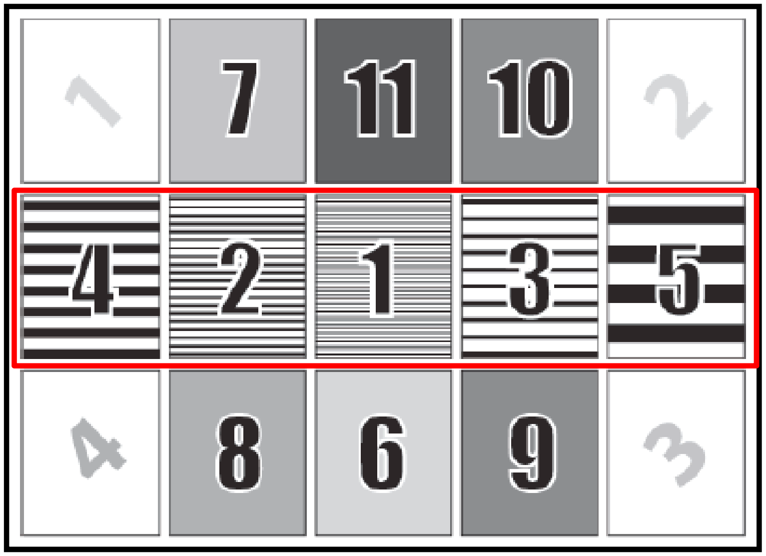
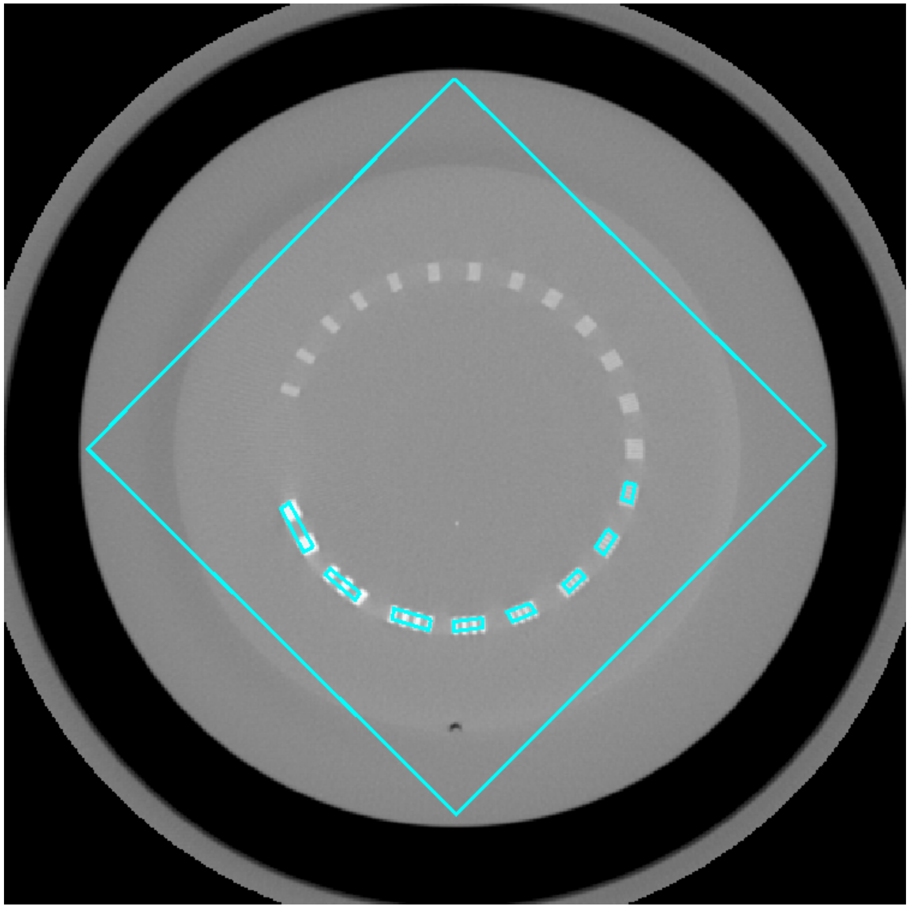
# PIPSpro – MTF




*Where is my delta function?*



CTP 528 – High Resolution Module

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# SWMTF – Key Concepts

- In imaging, for square wave patterns, as spatial frequency increases, variance decreases.
- The change in variance is proportional to the change in frequency response.
- The SWMTF is less susceptible to noise than Fourier transform-based methods.
- Provides a "Relative" MTF.

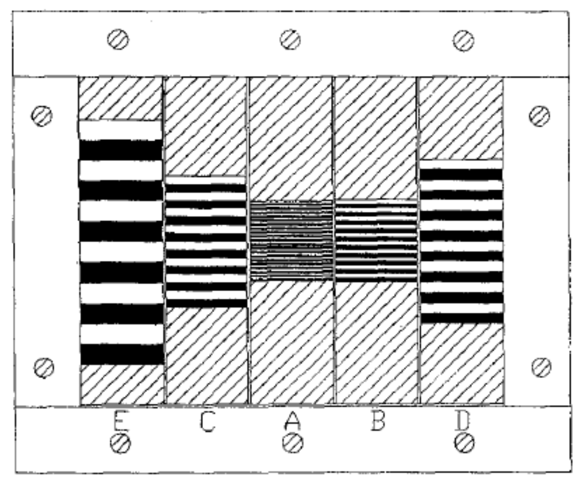
$$RMTF(f) = \frac{M(f)}{M(f_1)}$$

← Largest Bars

$$M^2(f) = \sigma_m^2(f) - \sigma^2(f)$$

Total Variance

Variance from Noise




Original Phantom

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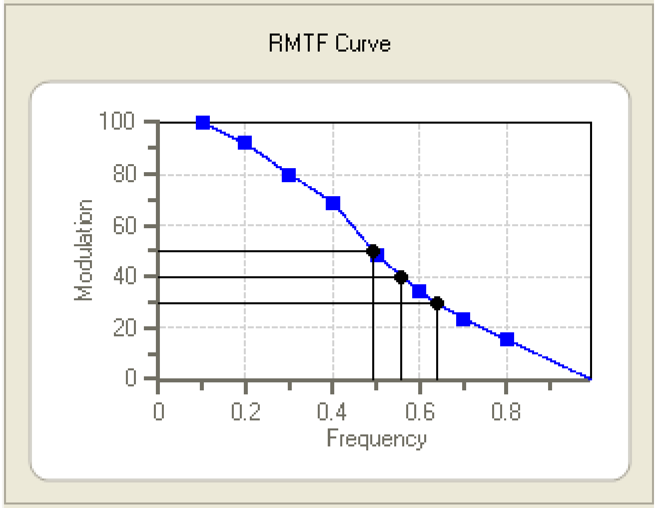
503, 504, 600

# CTP 528 – High Resolution Module

Spatial Resolution

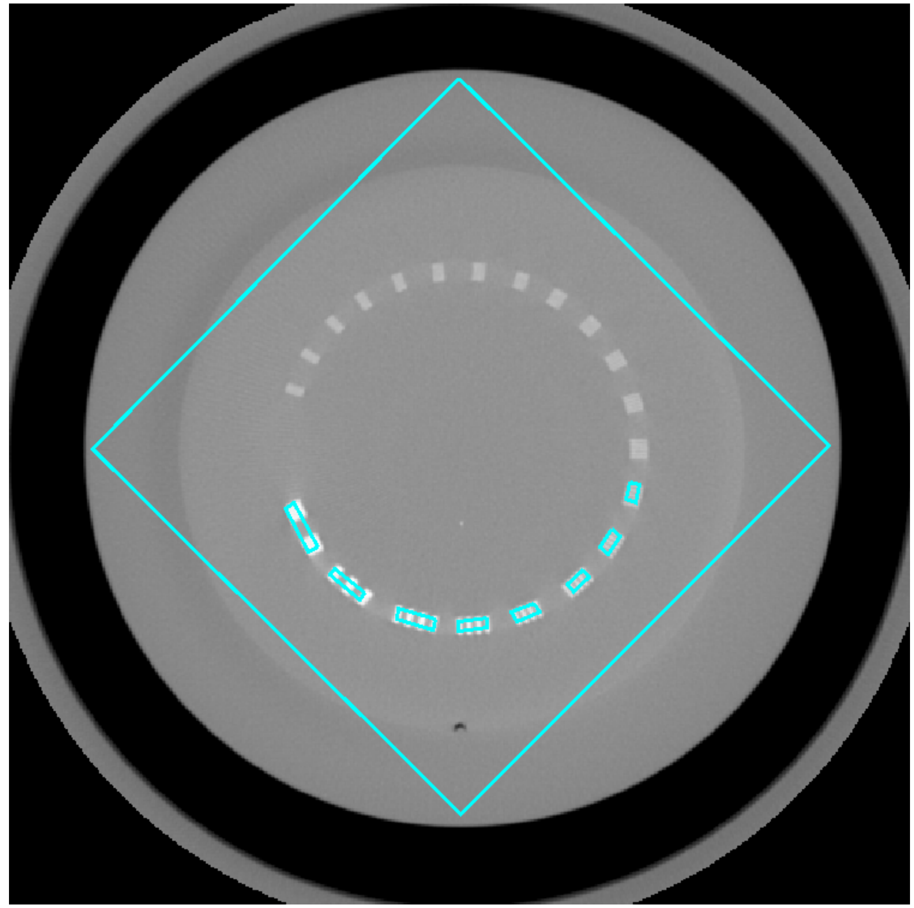
| F50 (lp/mm) | F40 (lp/mm) | F30 (lp/mm) |
|---|---|---|
| 0.493 | 0.559 | 0.638 |




$$RMTF(f) = \frac{\sigma_m(f)}{\sigma_m(f_1)} * 100\%$$

↑

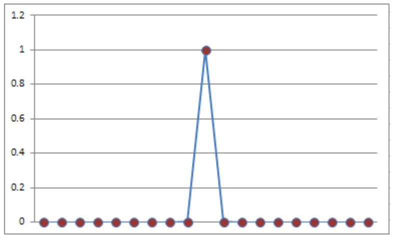
Largest Bars

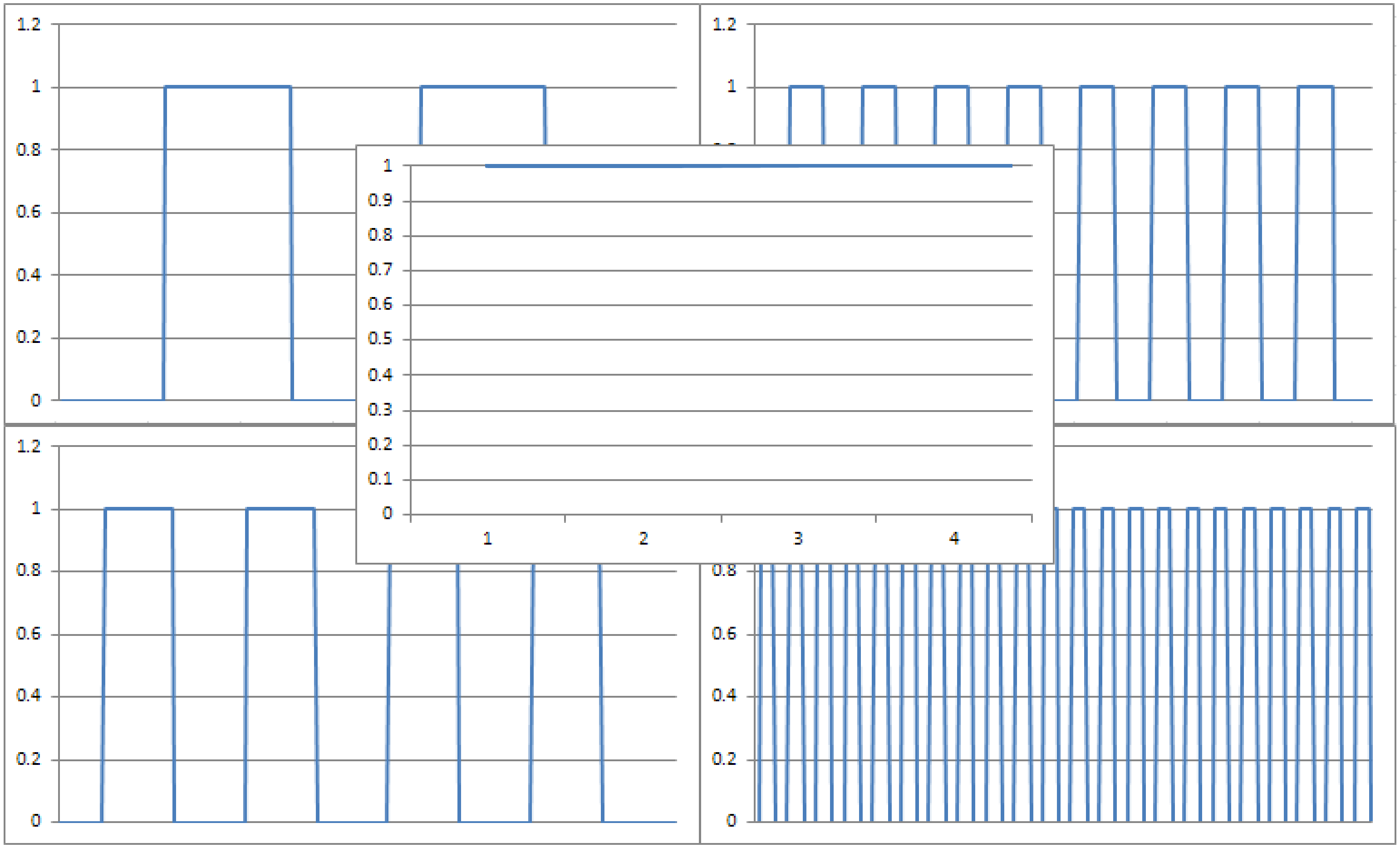


*For square wave patterns, as spatial frequency increases, variance decreases.*

# Sigma ~ 0

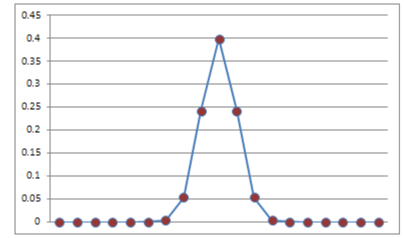
*The change in variance is proportional to the frequency response.*



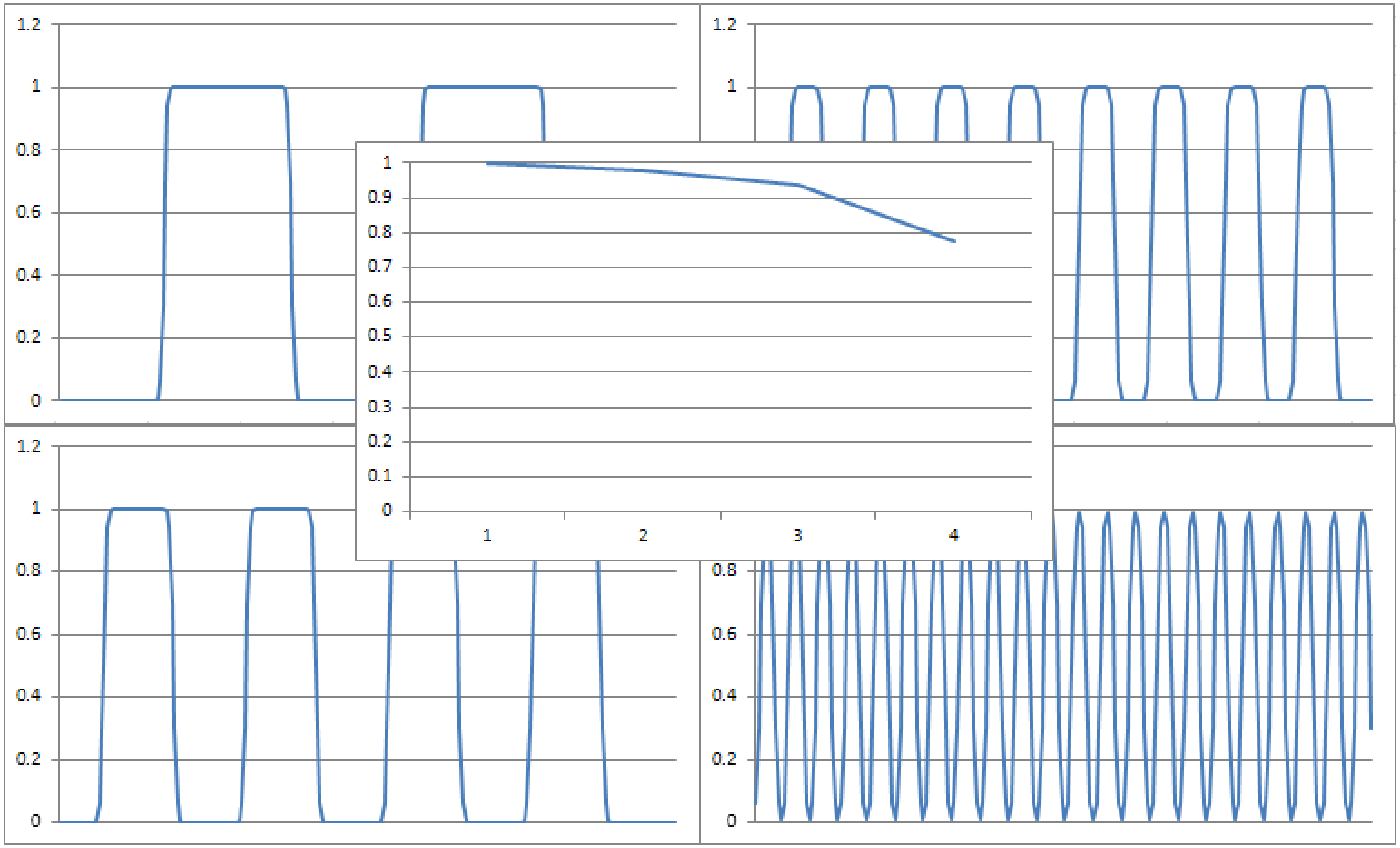



*Frequency response can be simulated by convolution of a Gaussian with "line pairs".*

# Sigma = 1

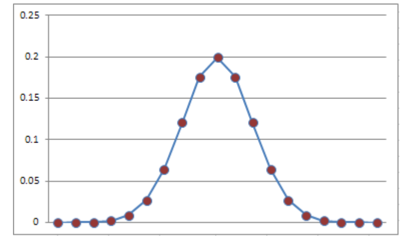


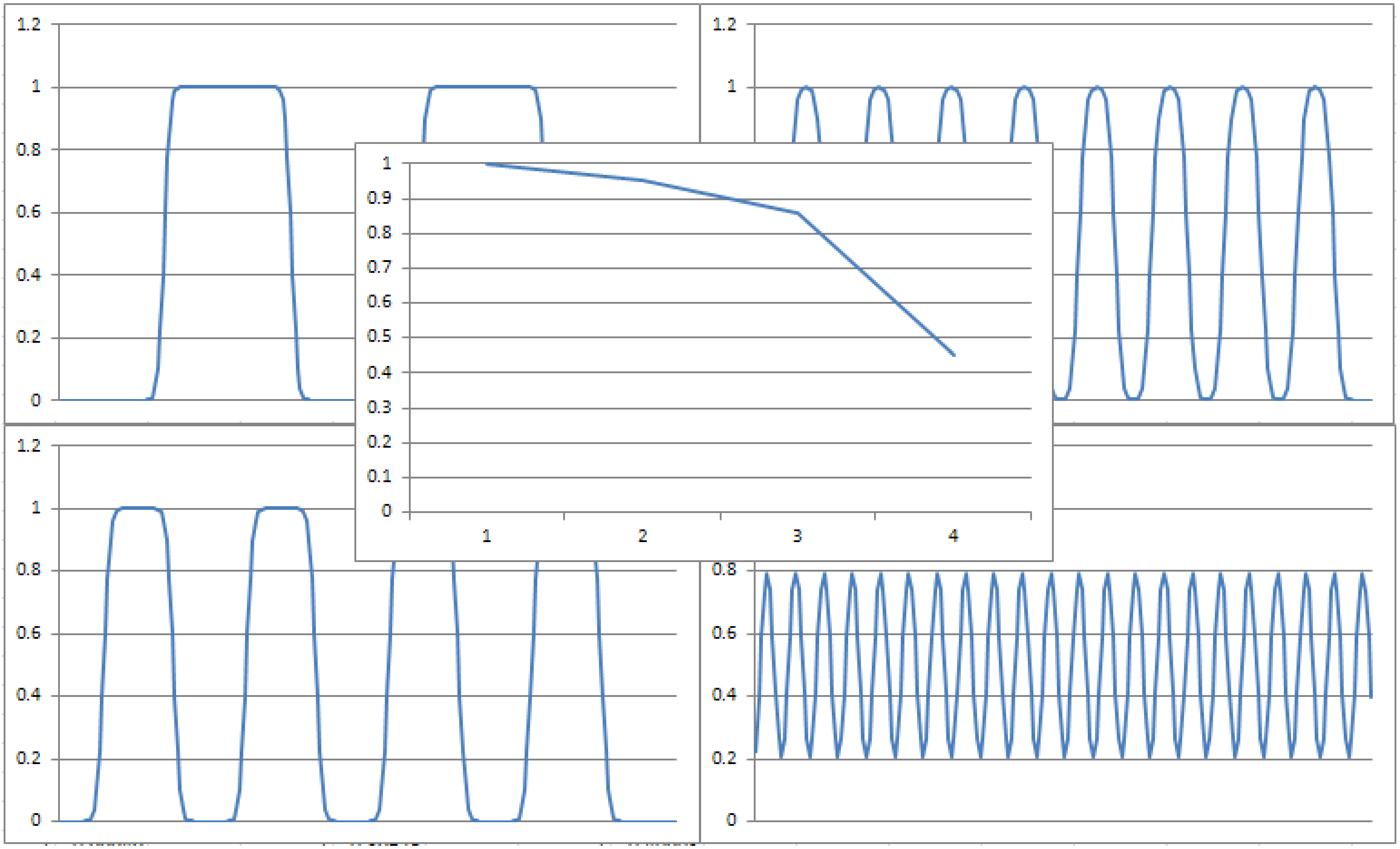
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0

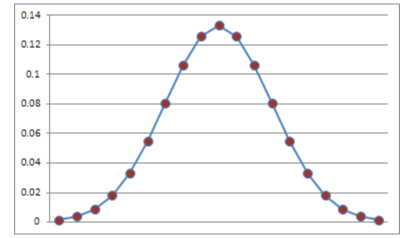
1.2
1
0.8
0.6
0.4
0.2
0
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
2
3
4

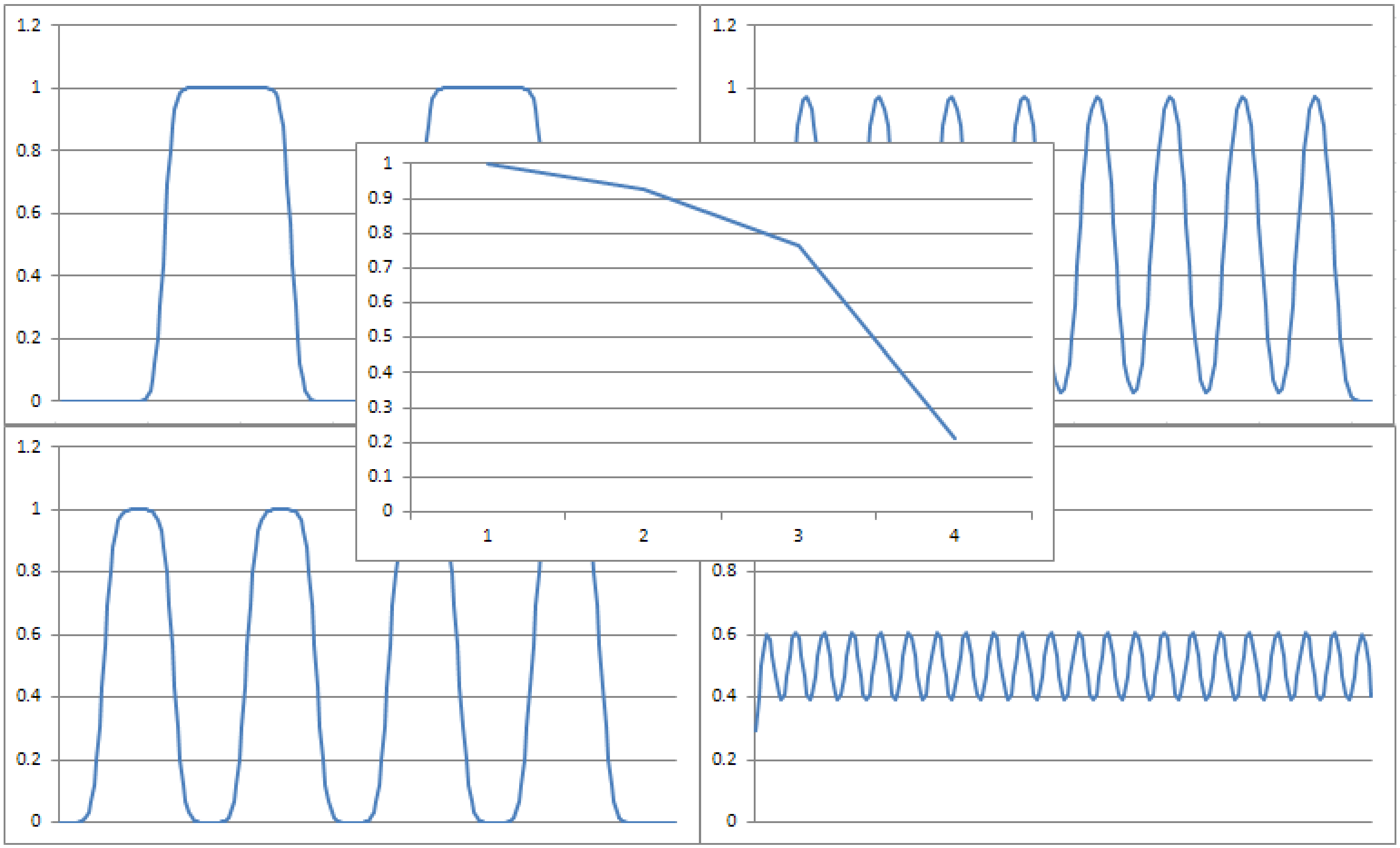
# Sigma = 2


0.25
0.2
0.15
0.1
0.05
0


1.2
1
0.8
0.6
0.4
0.2
0
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
2
3
4

# Sigma = 3

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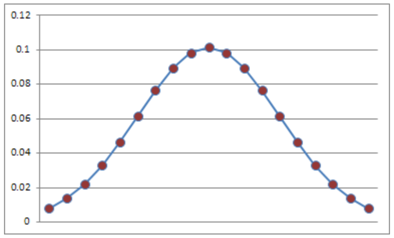
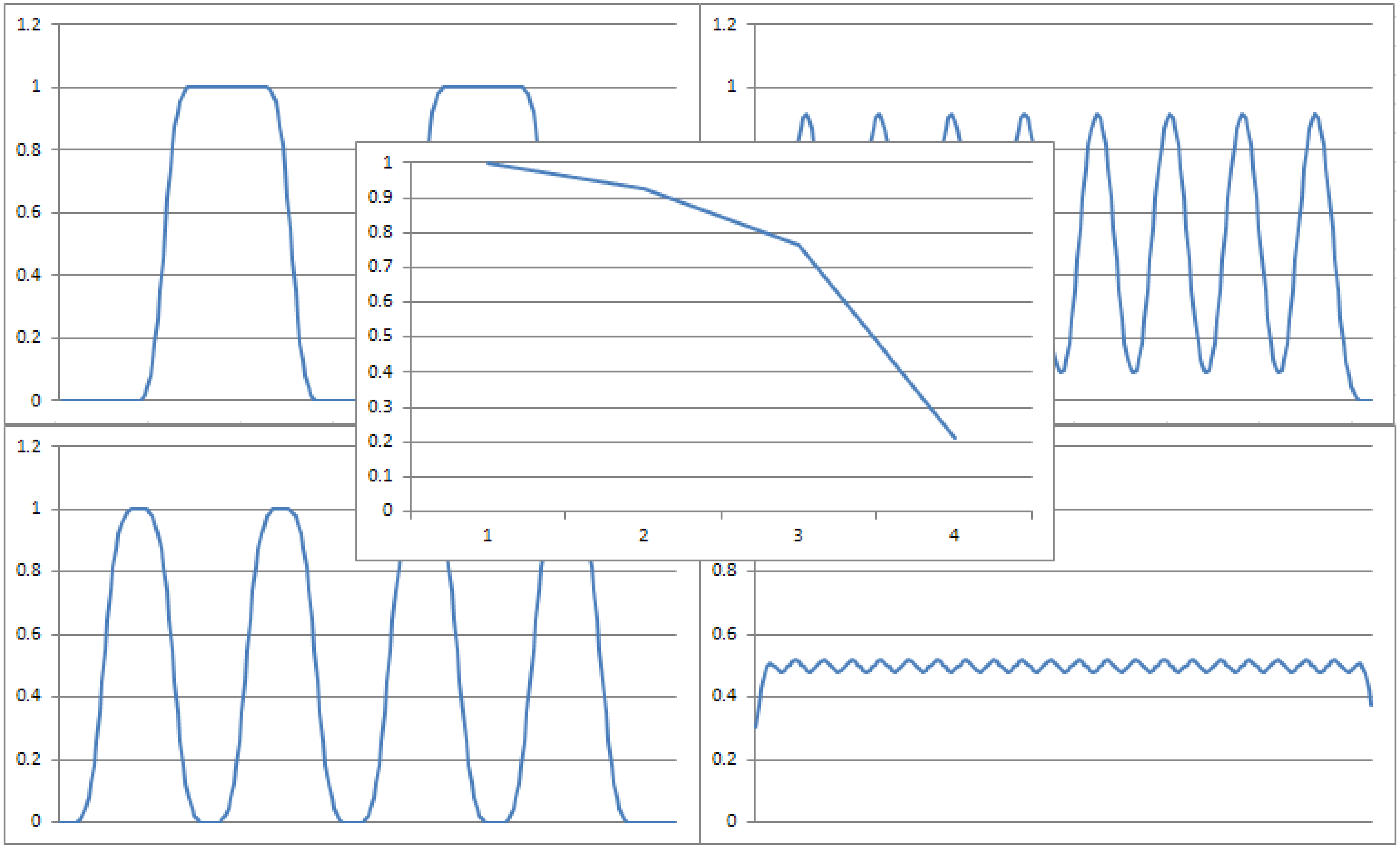
# Sigma = 4

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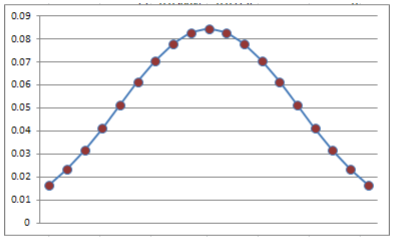
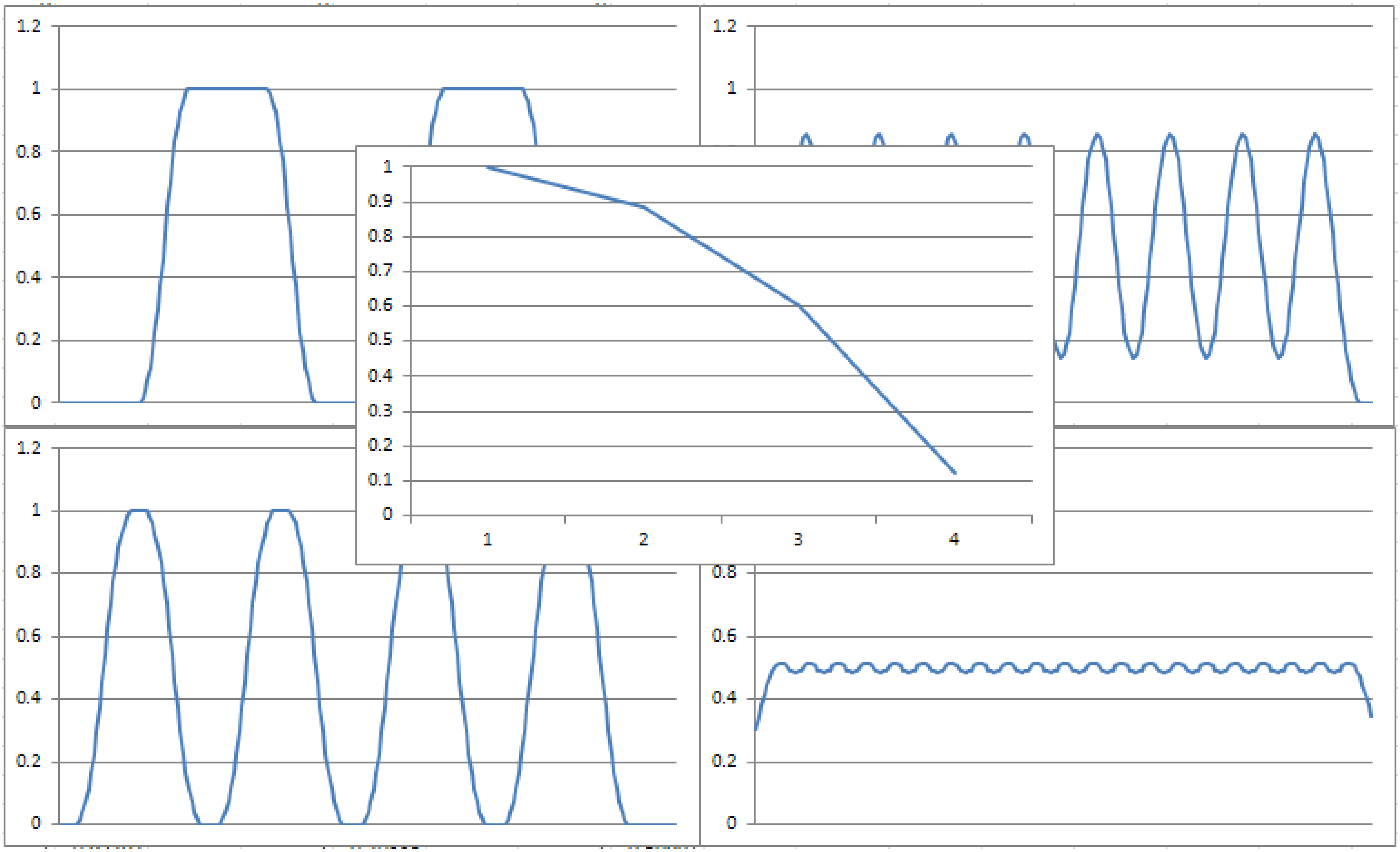
# Sigma = 5

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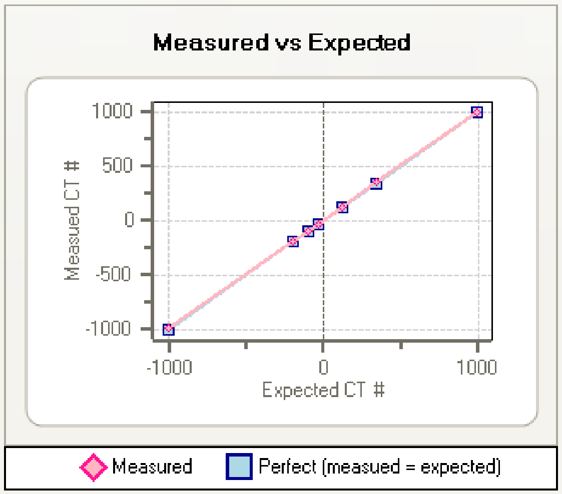
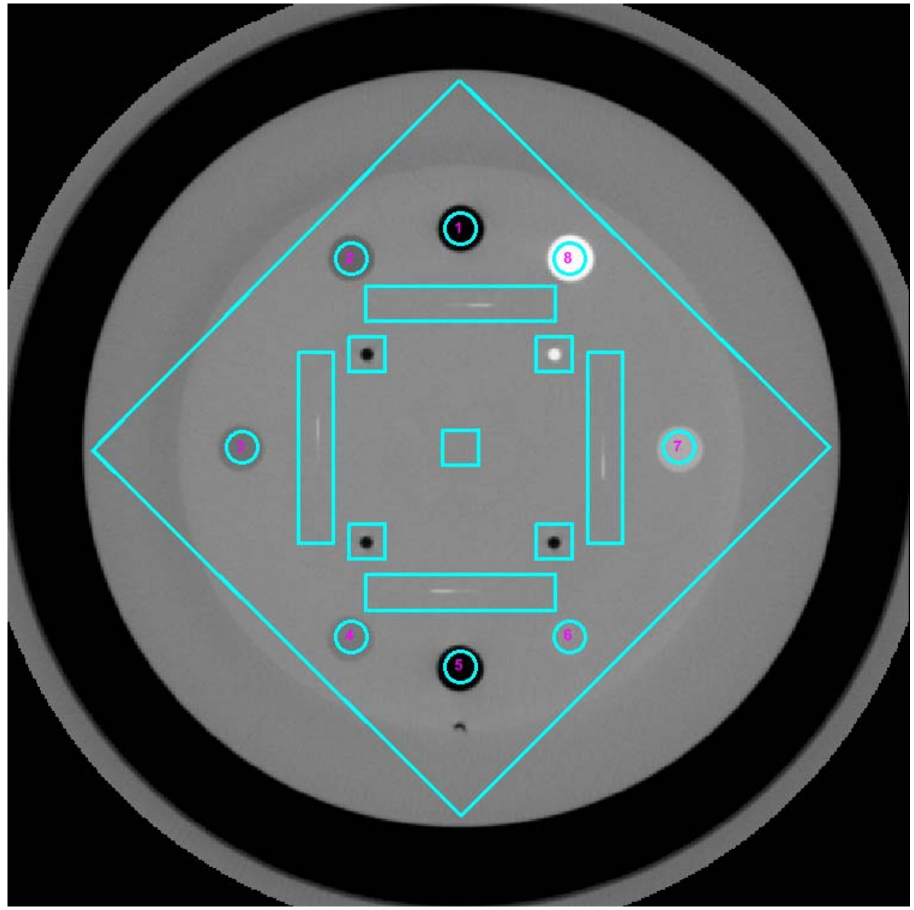
# CTP 404 – Hounsfield Number Constancy

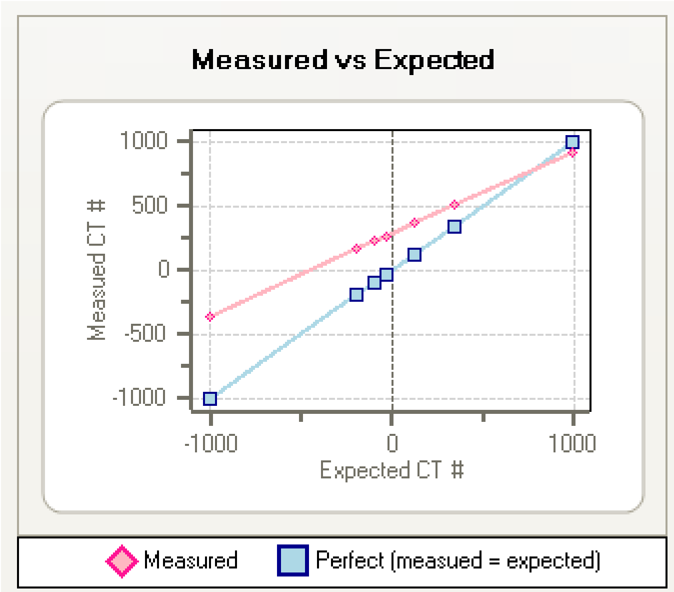
## HU Constancy

| ID | Material | Measured (HU) | Expected (HU) |
|---|---|---|---|
| 1 | Air | -996.848 | -1000.000 |
| 2 | PMP | -188.436 | -200.000 |
| 3 | LDPE | -97.652 | -100.000 |
| 4 | Polystyrene | -42.196 | -35.000 |
| 5 | Air | -995.640 | -1000.000 |
| 6 | Acrylic | 121.564 | 120.000 |
| 7 | Delrin | 359.056 | 340.000 |
| 8 | Teflon | 989.808 | 990.000 |



# HU Constancy




The “Expected” values may differ for your CBCT imager.

- Need for calibration
- Imager limitations

*Baselining functions in PIPSpro.*

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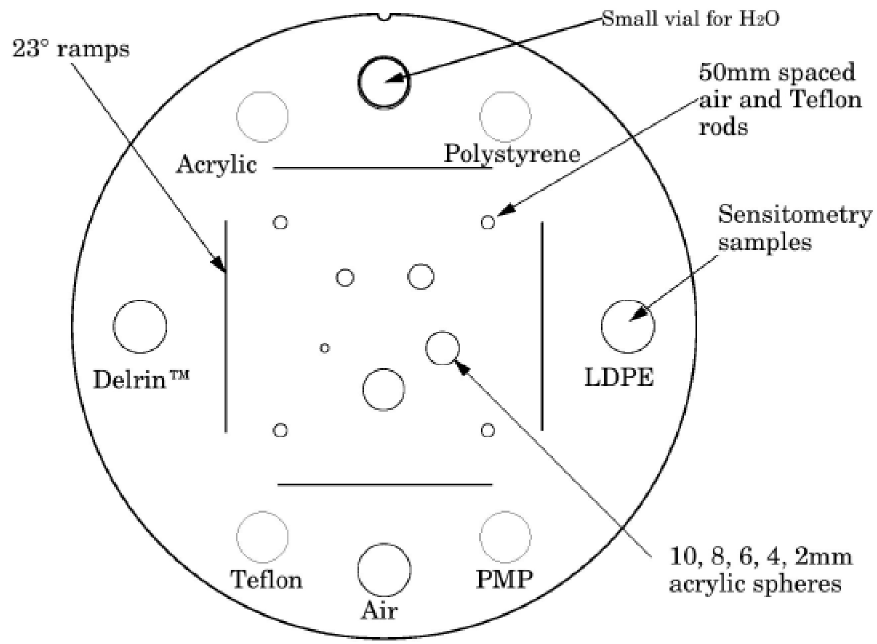
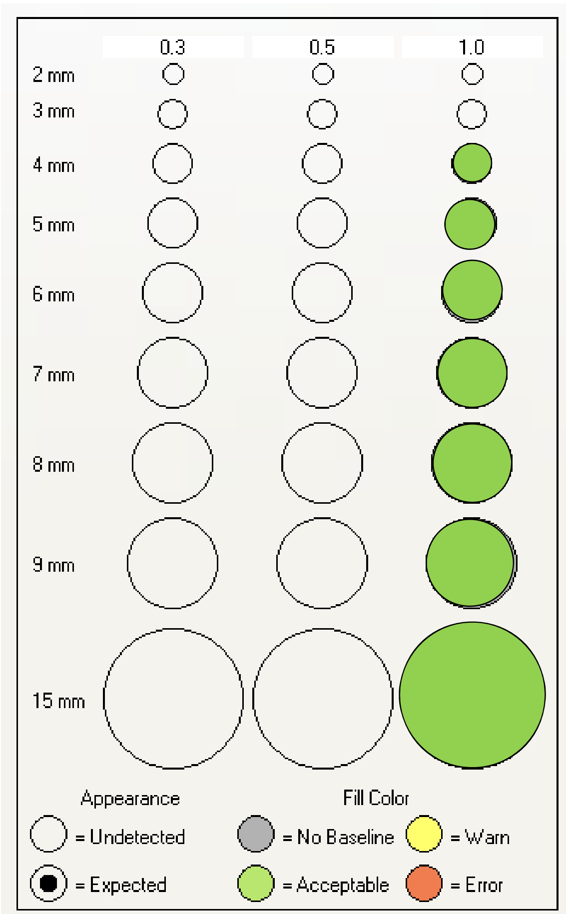
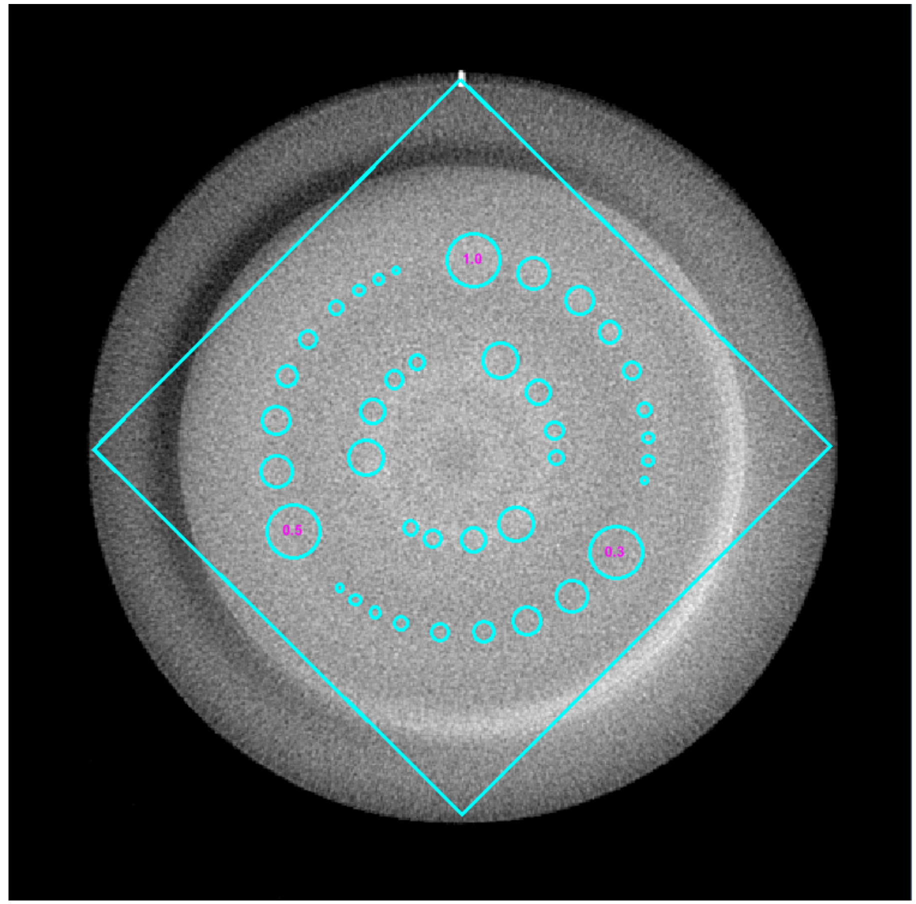



| Material | Formula | Est.[2] CT # (+/- 5%) |
|---|---|---|
| Air | .78 N, .21 O, .01 Ar | -1000 |
| PMP | $[C_6H_{12}(CH_2)]$ | -200 |
| LDPE | $[C_2H_4]$ | -100 |
| Water | $[H_2O]$ | 0 |
| Polystyrene | $[C_8H_8]$ | -35 |
| Acrylic | $[C_5H_8O_2]$ | 120 |
| Delrin® | Proprietary | 340 |
| Teflon® | $[CF_2]$ | 950 |

504, 600

# CTP 515 - Low Contrast Module




*These are normal results for CBCT low contrast detectability. 0.3% and 0.5% contrast may be detected with fan beam CT's (or maybe higher MU's).*

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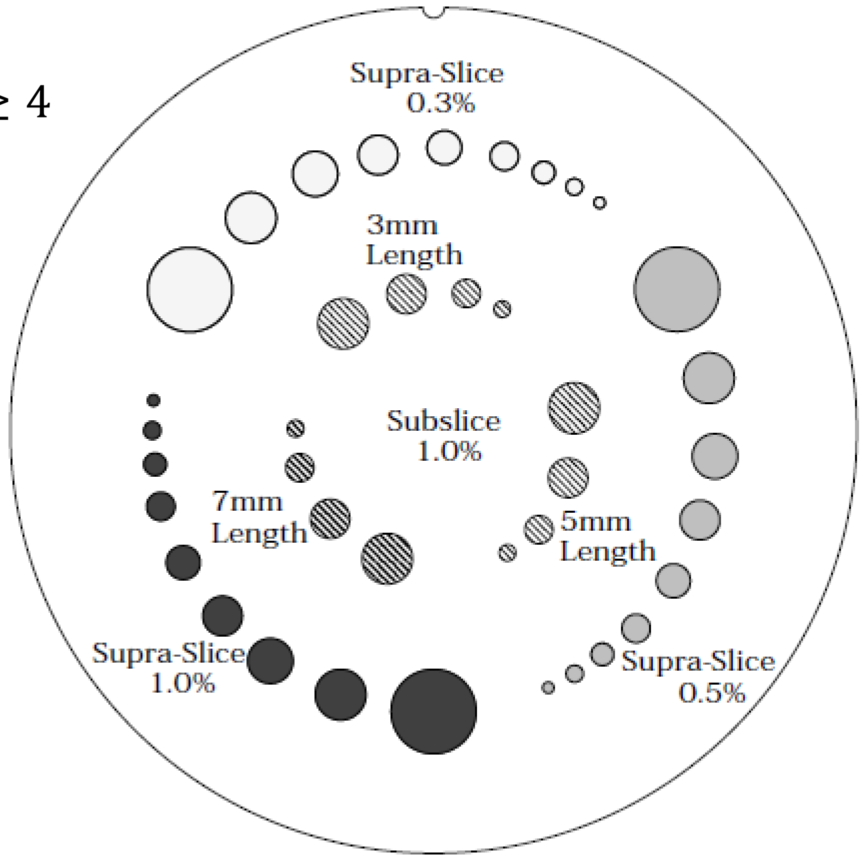
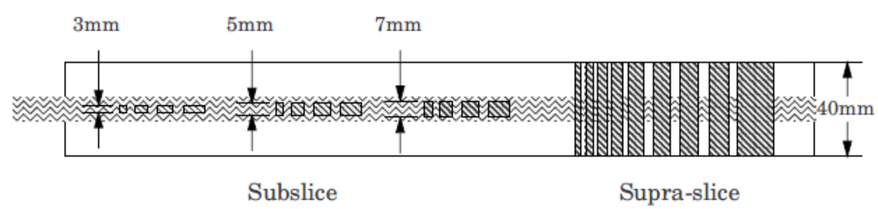
# Low Contrast Detectability

$$Detectability_{T/F} = \frac{\mu_{Target} - \mu_{Background}}{\sigma_{Background}} \geq 4$$

- Detectability occurs (is defined) when the "contrast to noise ratio" is greater than or equal to 4 (psychophysical basis).
- Subslice targets are ignored by PIPSpro.

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# Imaging Pointers

- Use imaging protocols similar to what you would use clinically.
- If you want to trend your QA metrics, always use the same imaging protocols, including fields of view.
- Smaller fields of view yield better results because pixel density per area increases with decreased field of view.
- Be sure to set up your phantoms correctly and accurately.

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# Bibliography

Lehmann J, Perks J, Semon S, Harse R, Purdy JA. Commissioning experience with cone-beam computed tomography for image-guided radiation therapy. J Appl Clin Med Phys. 2007 Jul 17;8(3):2354.

Stock M, Pasler M, Birkfellner W, Homolka P, Poetter R, Georg D. Image quality and stability of image-guided radiotherapy (IGRT) devices: A comparative study. Radiother Oncol. 2009 Oct;93(1):1-7

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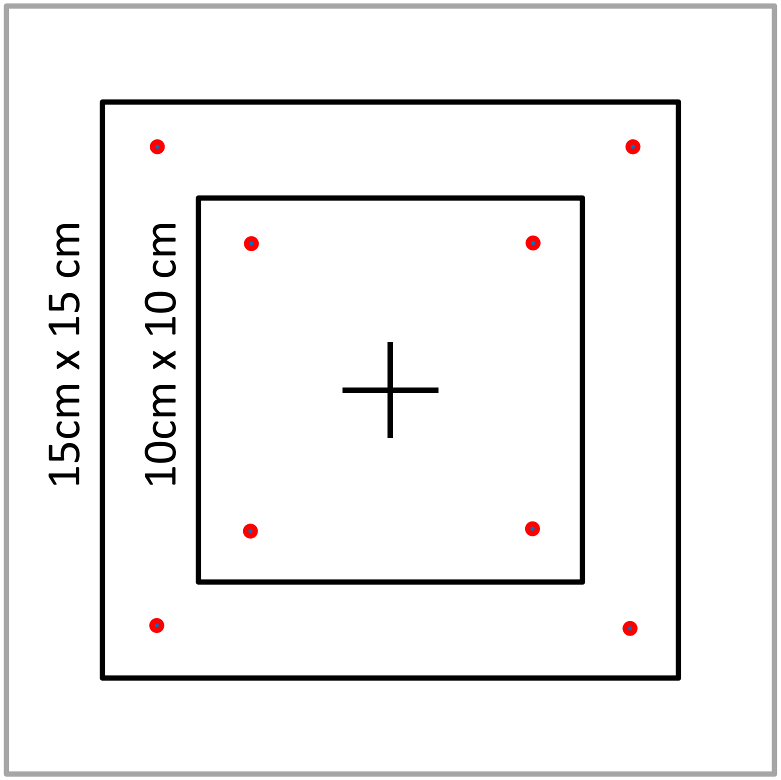
# Scaling (Planar Only)- FC-2 Phantom




The MLC phantom or FC-2 phantom can be used for this purpose as can any other phantom that has fiducials set at a known distance from one another.

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