Comparison of assessment techniques for CT scanner spatial resolution measurement

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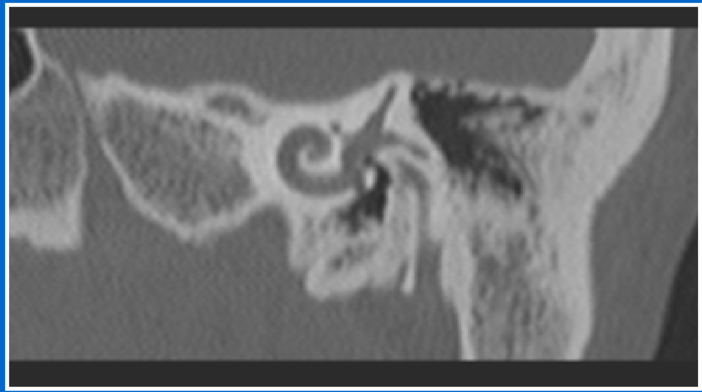
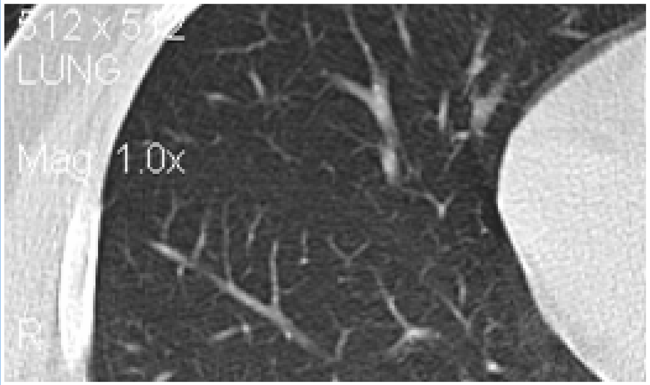
Why assess spatial resolution?

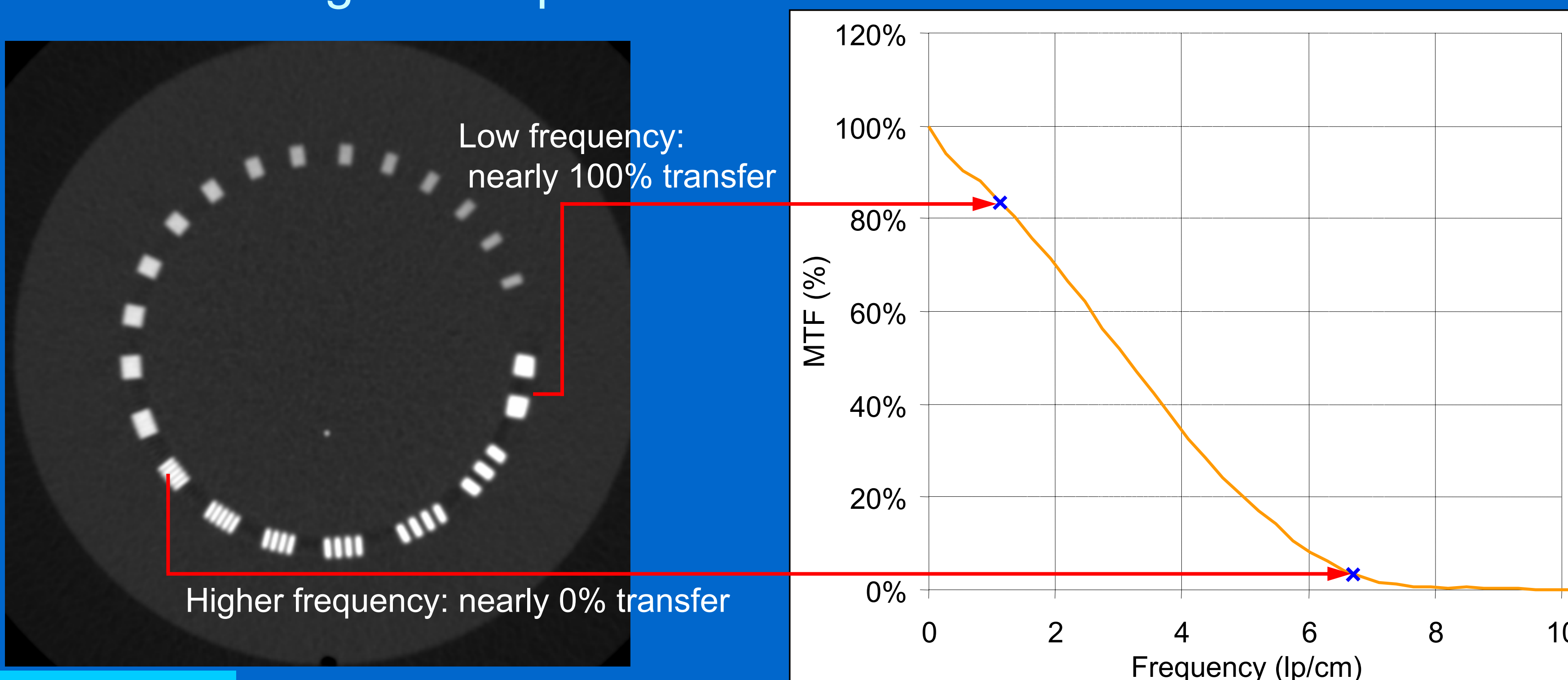
- Ability to visualise small objects governed by the spatial resolution of an imaging system
- CT generally prioritises depiction of low contrast features
  - Able to see attenuation differences of approx 1%
  - Typical spatial resolution of ~6-8 lp/cm
- Some CT applications demand high spatial resolution
  - Bone and lung imaging in particular
  - CT scanner typically has limiting spatial res. of 12-20+ lp/cm
- Need to be able to assess suitability for imaging task





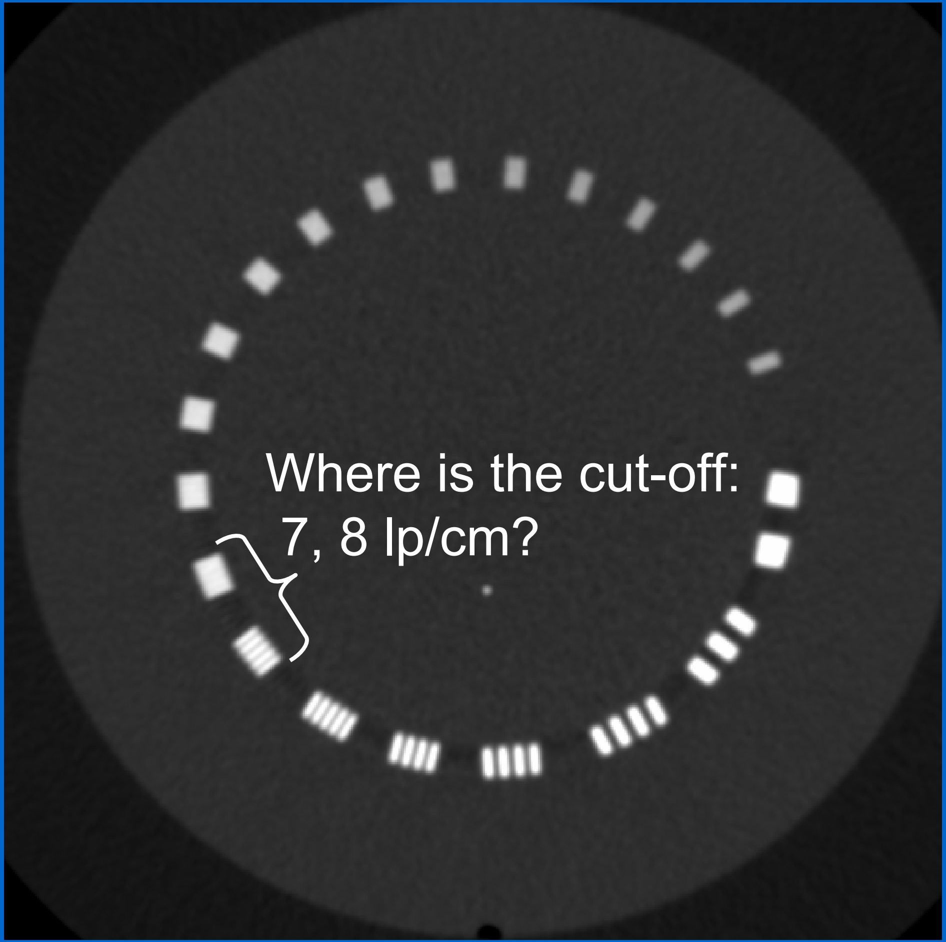
Resolution measures

- Limiting visual resolution
  - Given in lp/cm, cycles/cm or detail size in mm
- Modulation transfer function
  - Percentage transfer of spatial information from object to image over range of frequencies



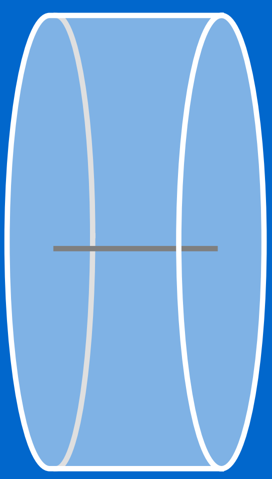
Methods for measurement (1)

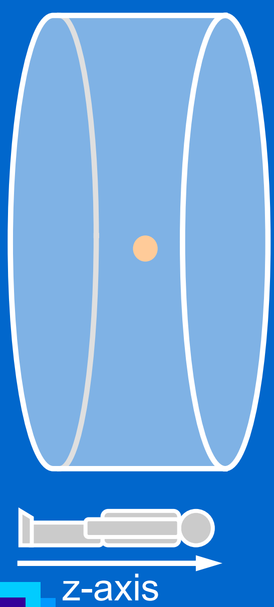
- Subjective techniques
  - Limiting resolution using line pairs etc.
  - Commonly used, but have limited accuracy and repeatability

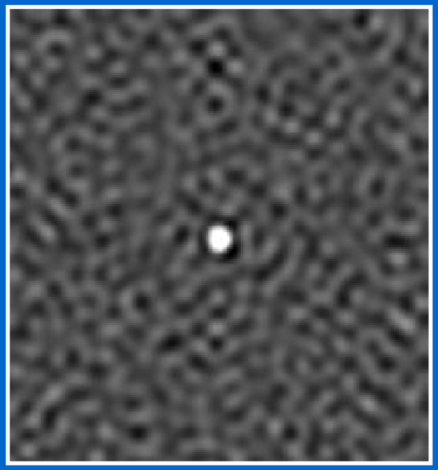


Methods for measurement (2)

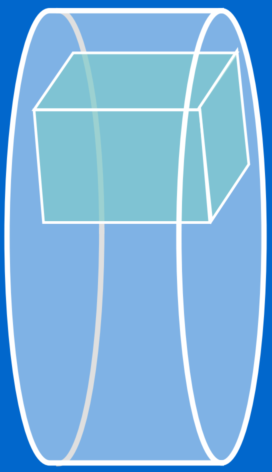
- Objective techniques
  - Indirect method using line pairs
    - Droege and Morin, can be measured at scanner console
  - Point sources e.g. metal wires and beads
    - Point spread function measured
  - ‘Edge’ method, currently used by ImPACT
    - CT number change of Teflon edge in water measured







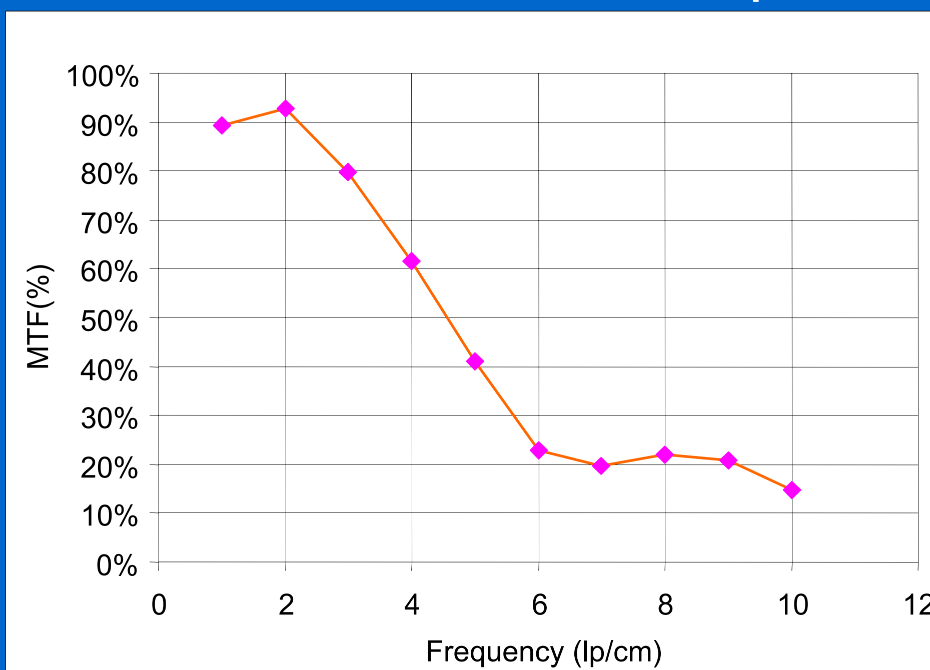
Point source

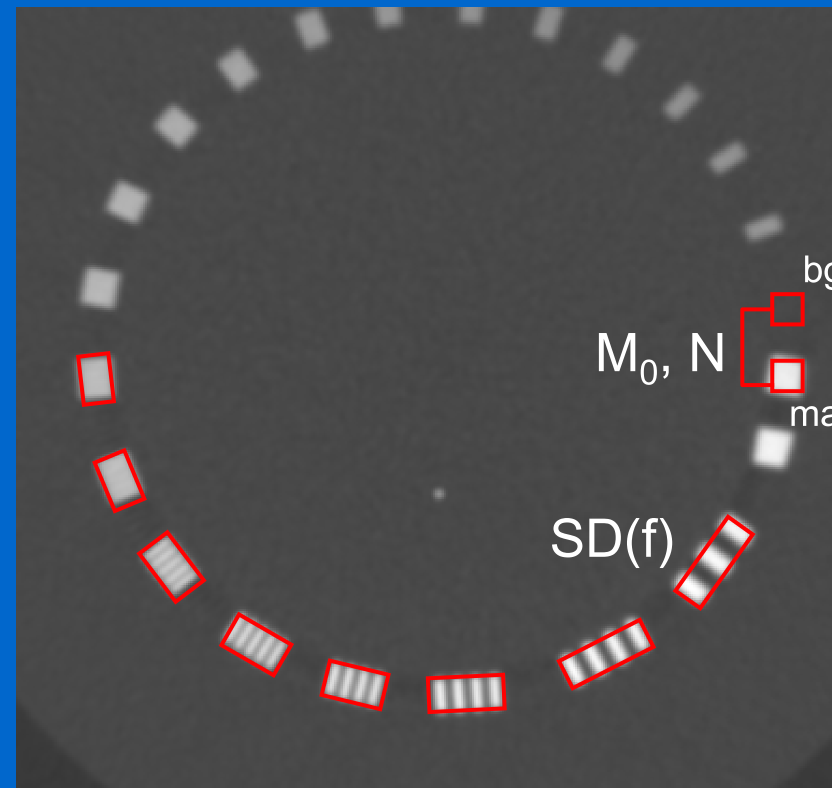


Edge method

Droege and Morin, Med Phys 9(5):758-780

- Measure CT# and SD of background (bg) and max CT#
- M_0 = Mean of bg and max CT#
- N = Mean noise
  = √(bg² + max CT#²) SD
- Measure SD of each bar pattern

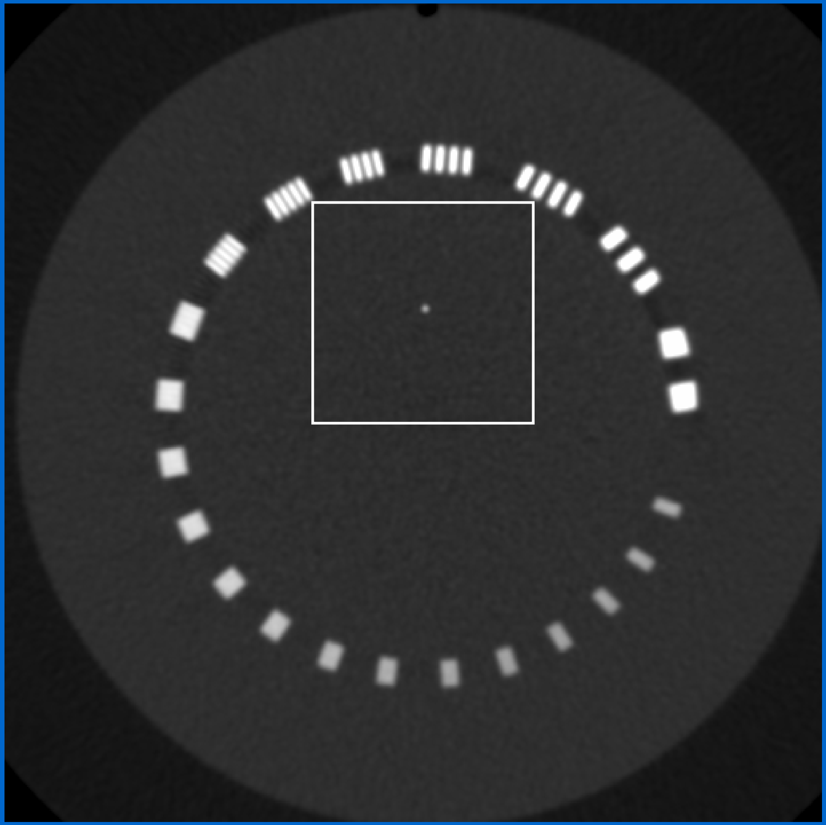


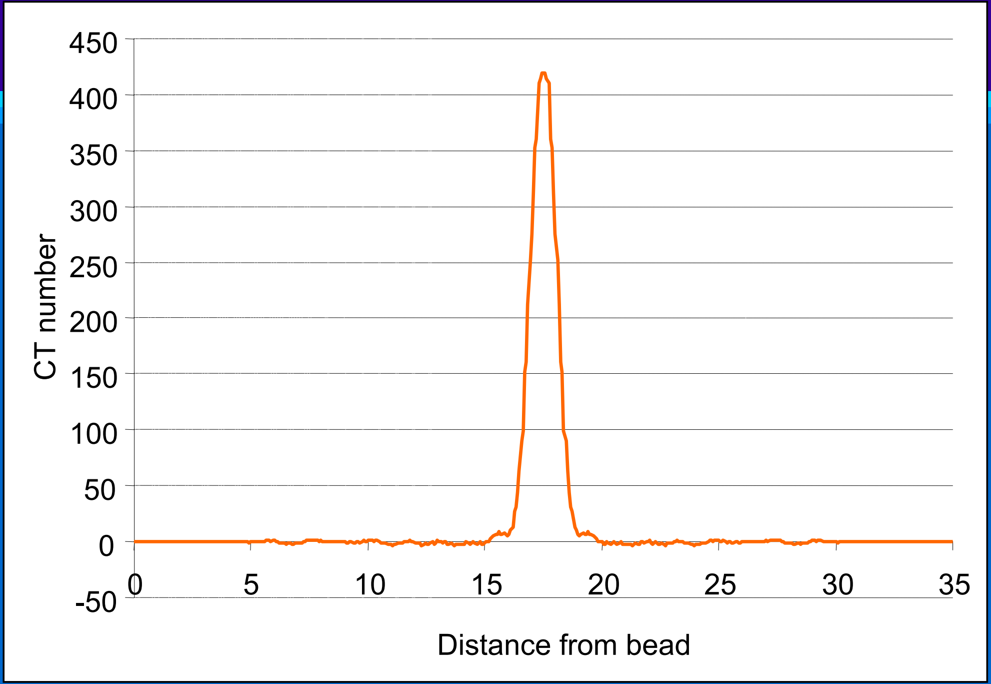


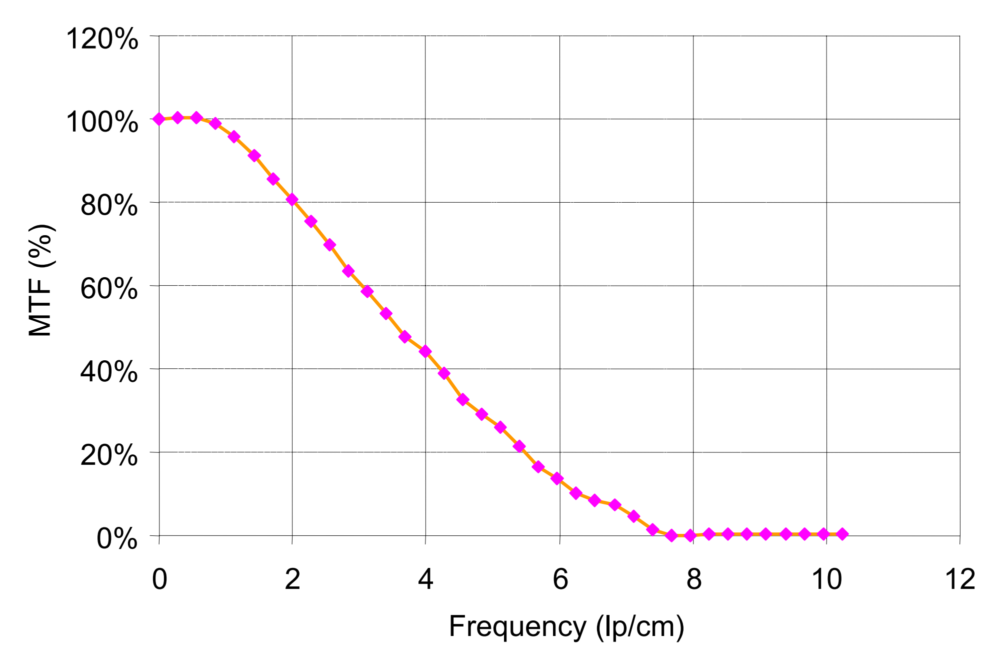
$$MTF(f) = \frac{\sqrt{2}}{4}\pi\frac{\sqrt{SD(f) - N}}{M_0}$$

Point sources

- Wire or bead on uniform background
  - Recon with small field of view, FT(PSF) -> MTF

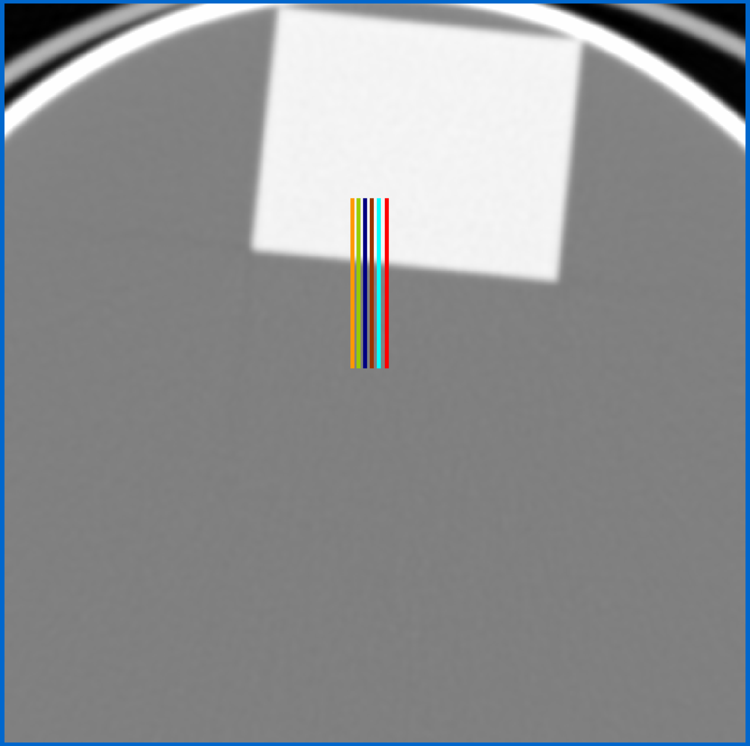


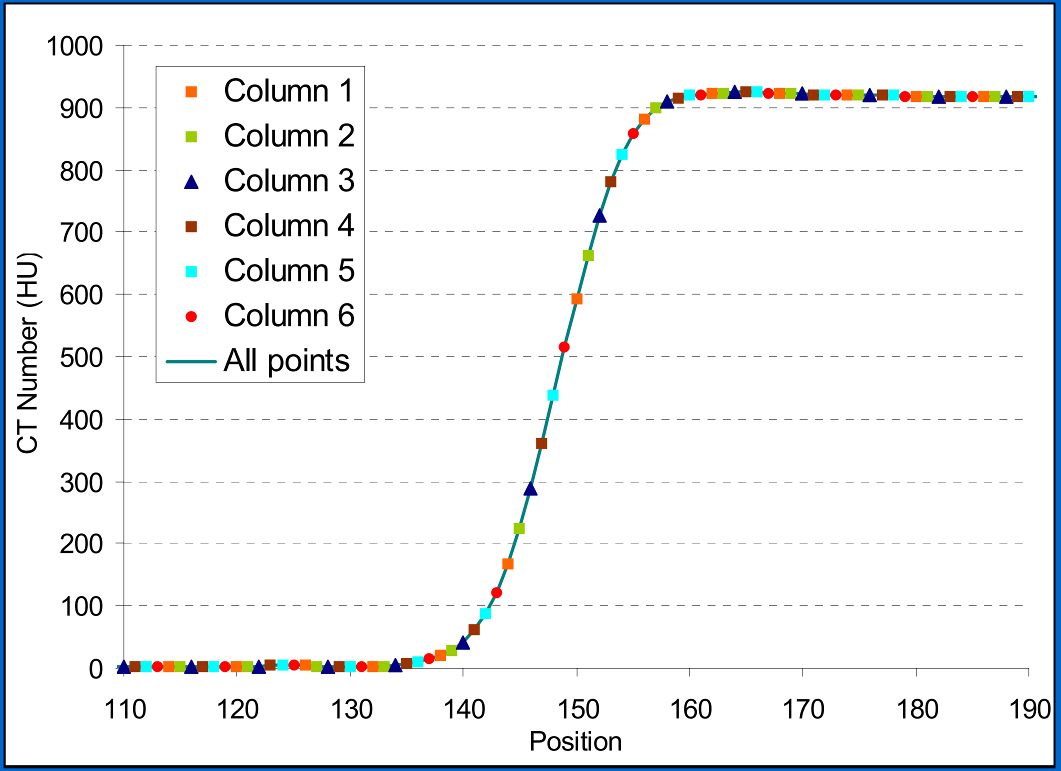




Edge method

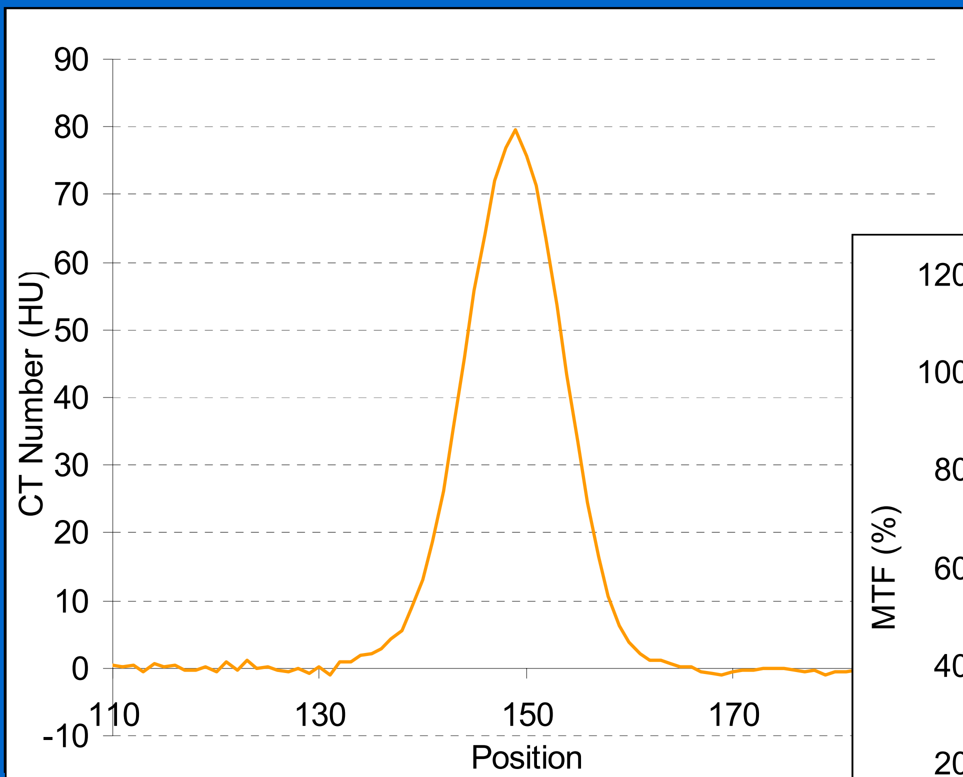
- Edge spread function measured
  - Angled edge oversamples ESF

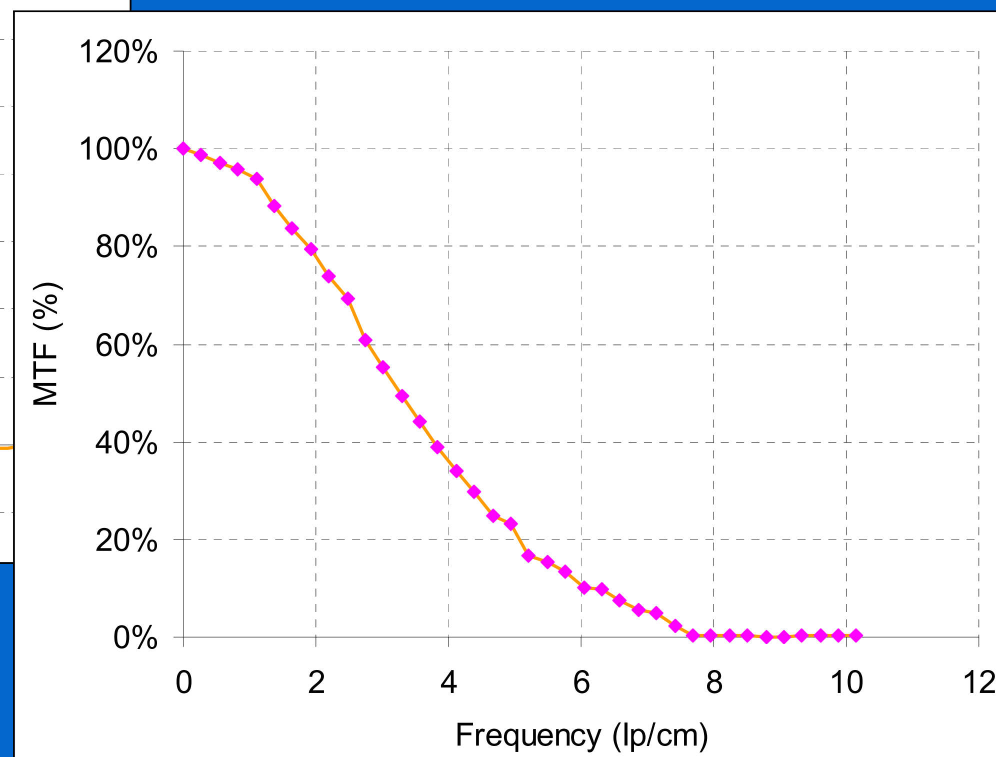




Edge method (2)

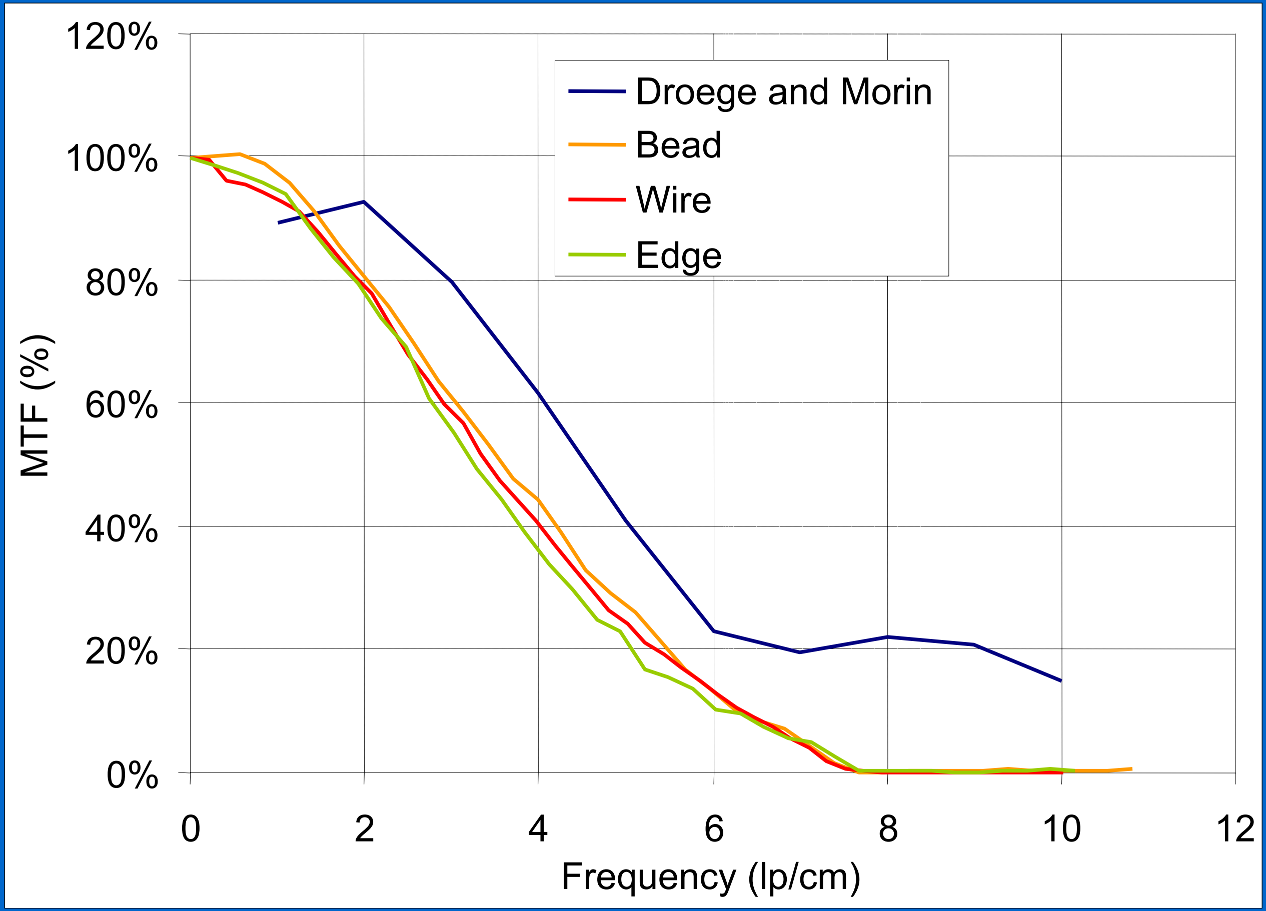
- Differentiate ESF -> PSF
  - FT(PSF) -> MTF





Results compared

- Results for the same scanner using a routine filter, showing each analysis method

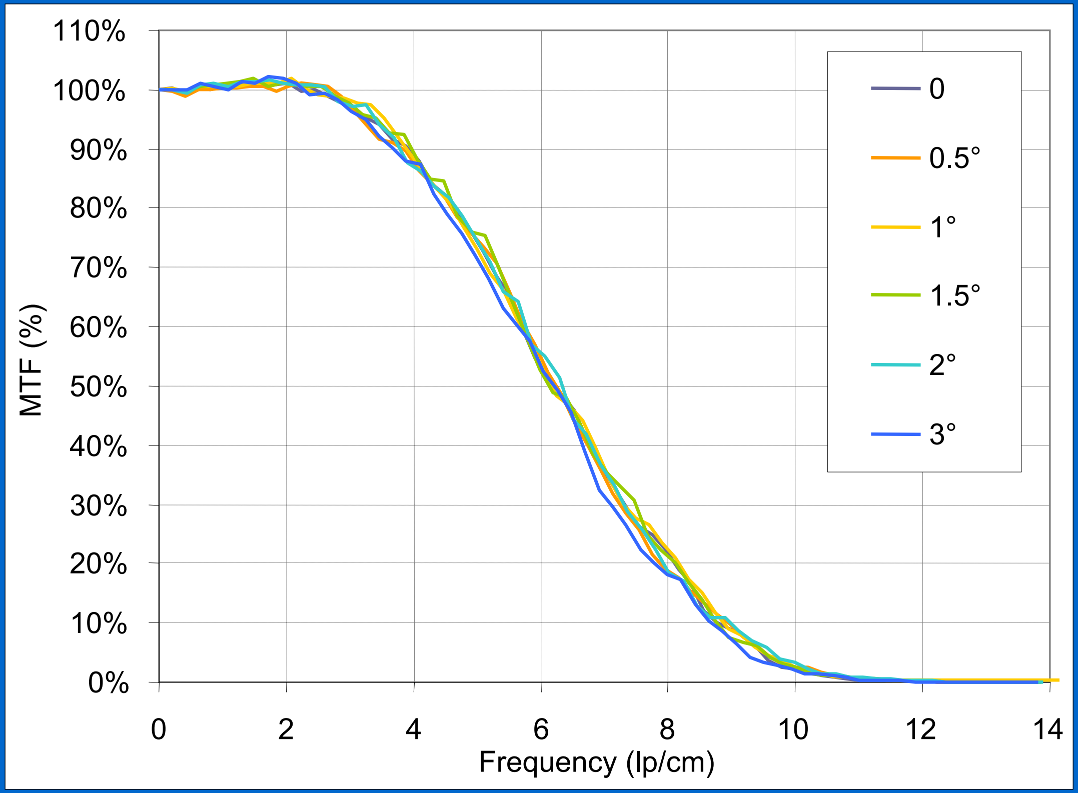


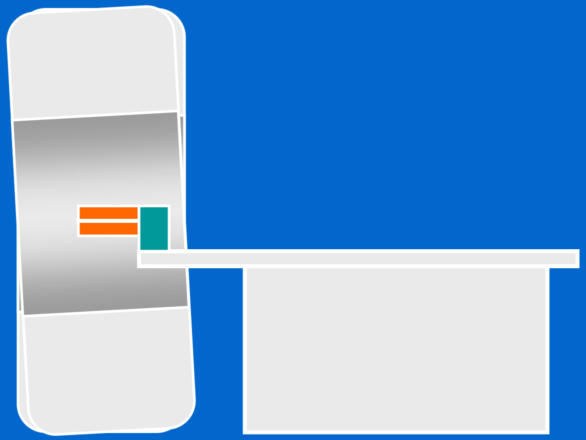
Issues with bead, wire and edge

- Phantom alignment for edge and wire
- Noise in MTFs
- Bead and wire contrast – noise in MTFs
- Background subtraction for wire and edge
- Asymmetric edge spread functions
- Overshoot of PSF with edge method

Phantom alignment

- Wire and edge phantoms need alignment along z-axis
  - Misaligned phantoms blur point or edge
  - Following results show effect of tilting gantry by up to 3°

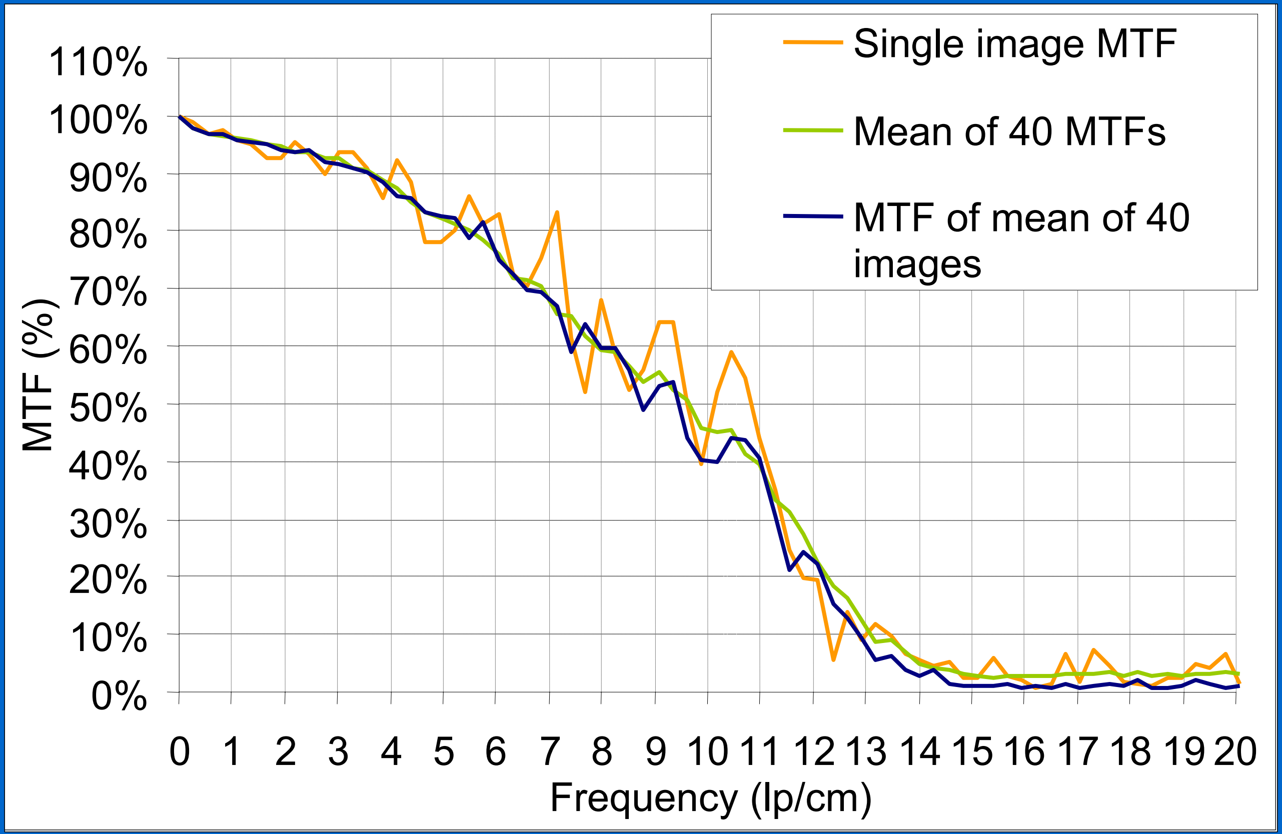




Angle	MTF_{50}	MTF_{10}	MTF_{2}
0	6.2	8.7	10.0
0.5°	6.2	8.9	10.3
1°	6.1	8.8	10.1
1.5°	6.1	8.7	10.1
2°	6.3	8.9	10.2
3°	6.1	8.6	9.9

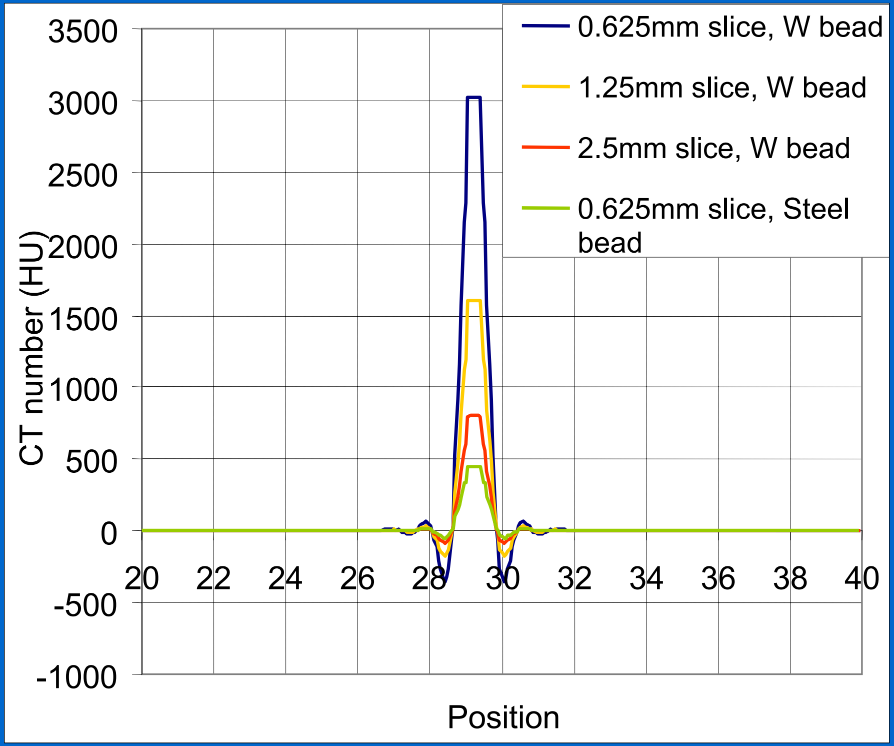
Noise in MTFs

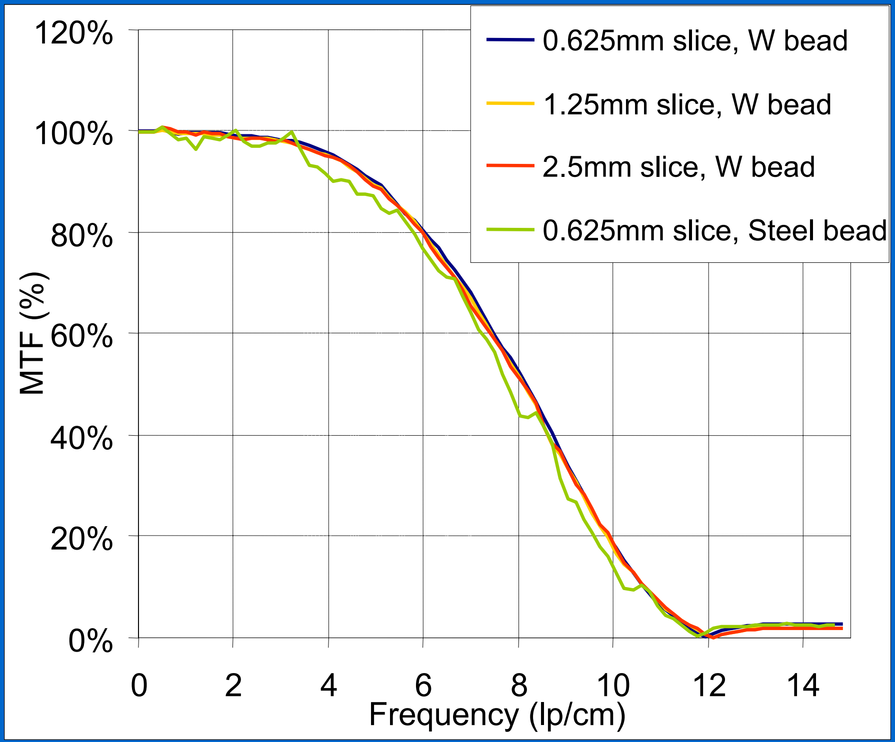
- Edge method gives noisier MTFs than direct PSF methods
  - Differentiated ESF is noisier than direct PSF measurements
  - Worse for sharp filters
- Can be reduced using multiple images



Bead and wire contrast – noise in MTFs

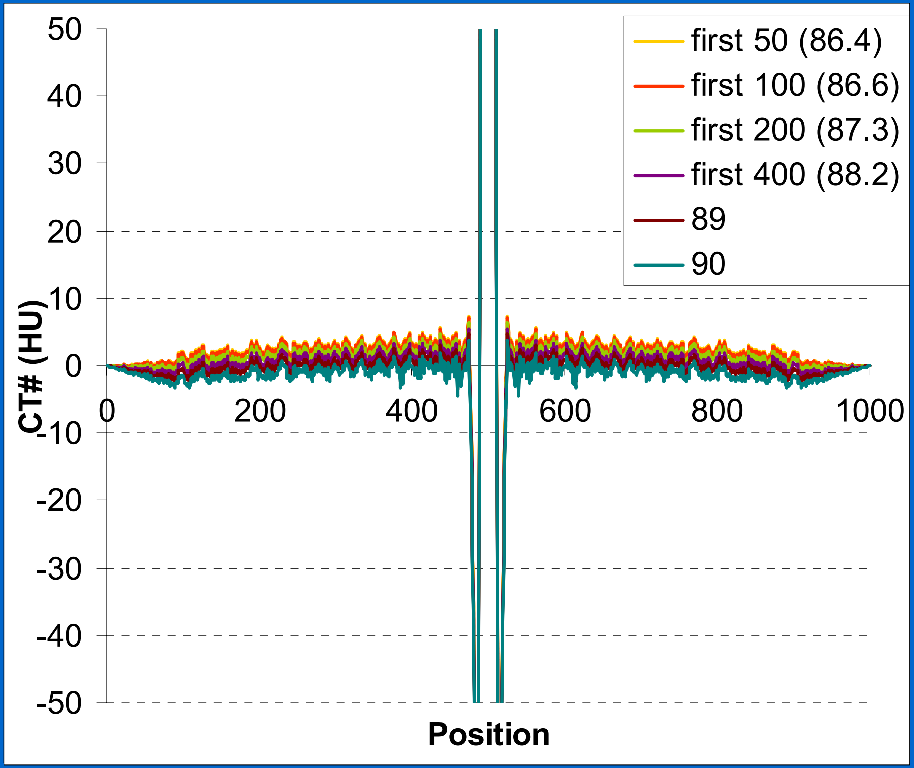
- Wire contrast independent of slice width
- Bead contrast depends on slice width
- Ideally want high contrast without saturating CT# range
  - Best way to consistently achieve this is with a wire

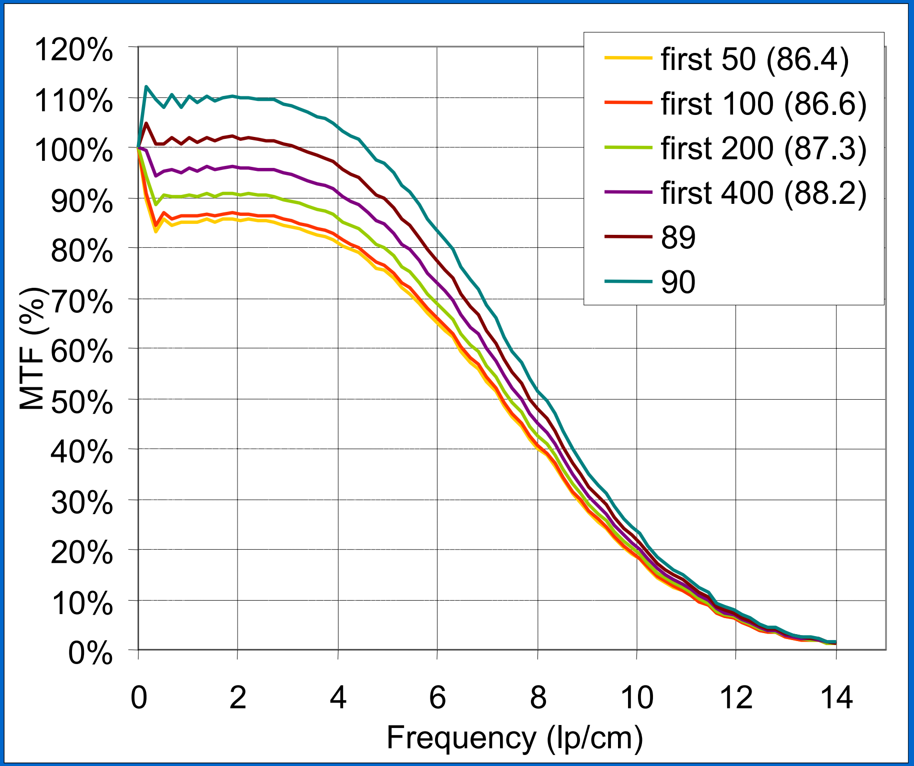




Background subtraction for wire and edge

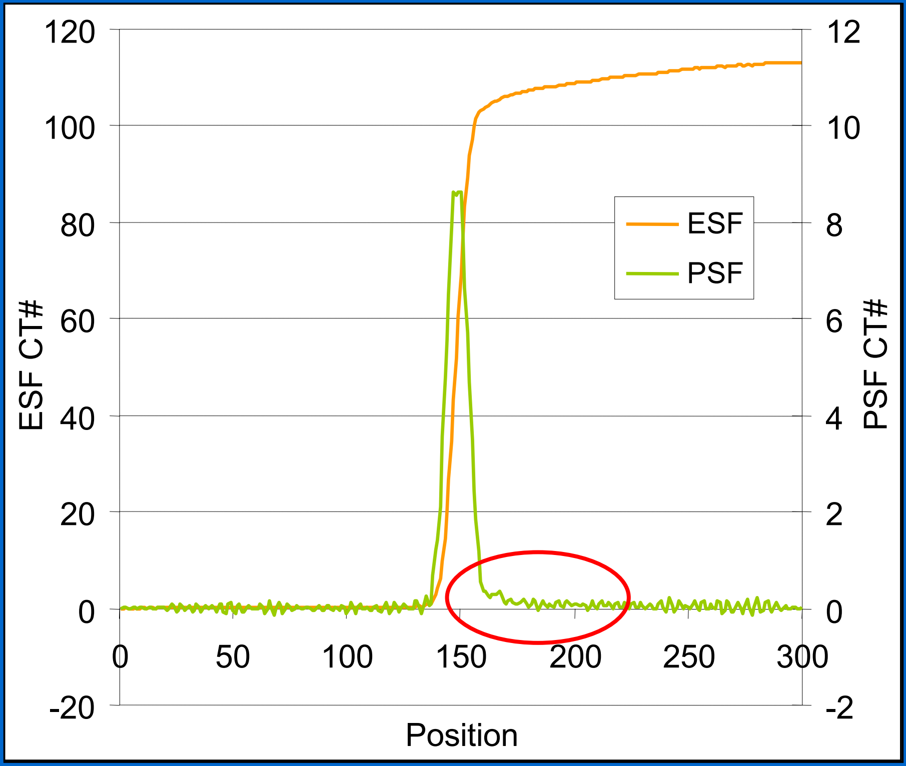
- MTF is normalised to value at 0 frequency (DC value)
  - Correct background subtraction is important. Following example uses different methods, giving b/g values 86-90 HU

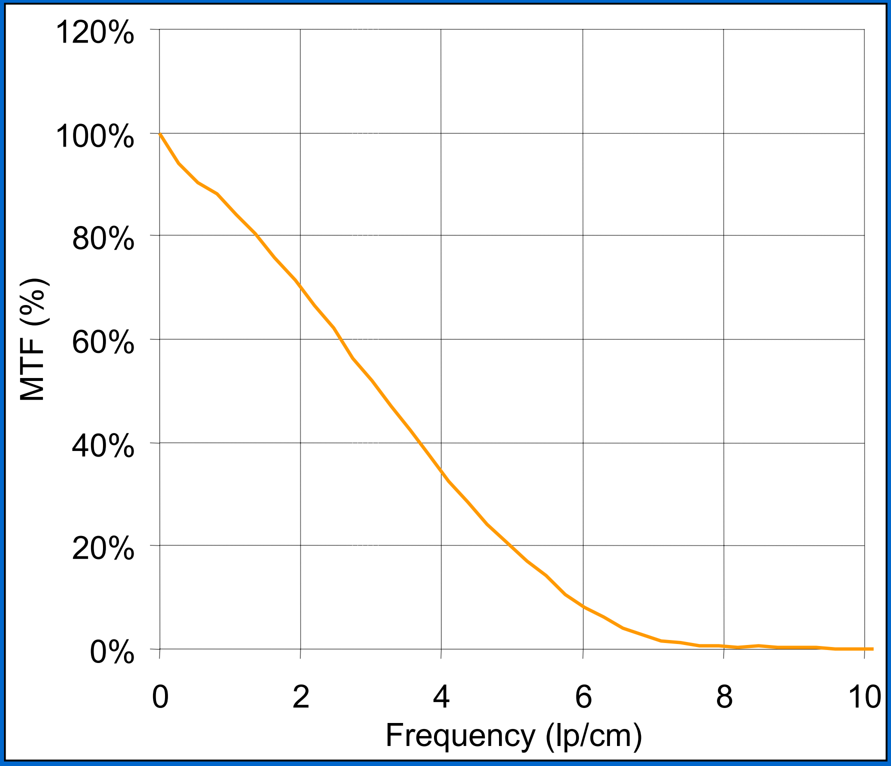




Asymmetric ESFs

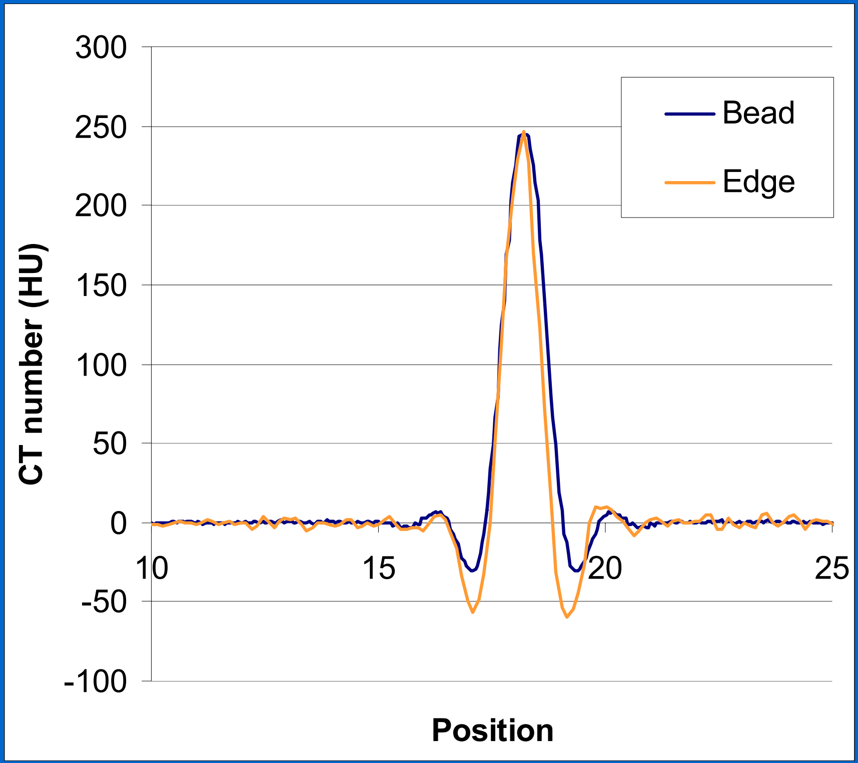
- Edge spread function theoretically differentiates to give PSF
  - In practice, the ESF is not symmetric due to non-linear effects (e.g. beam hardening, bone artefact reduction)

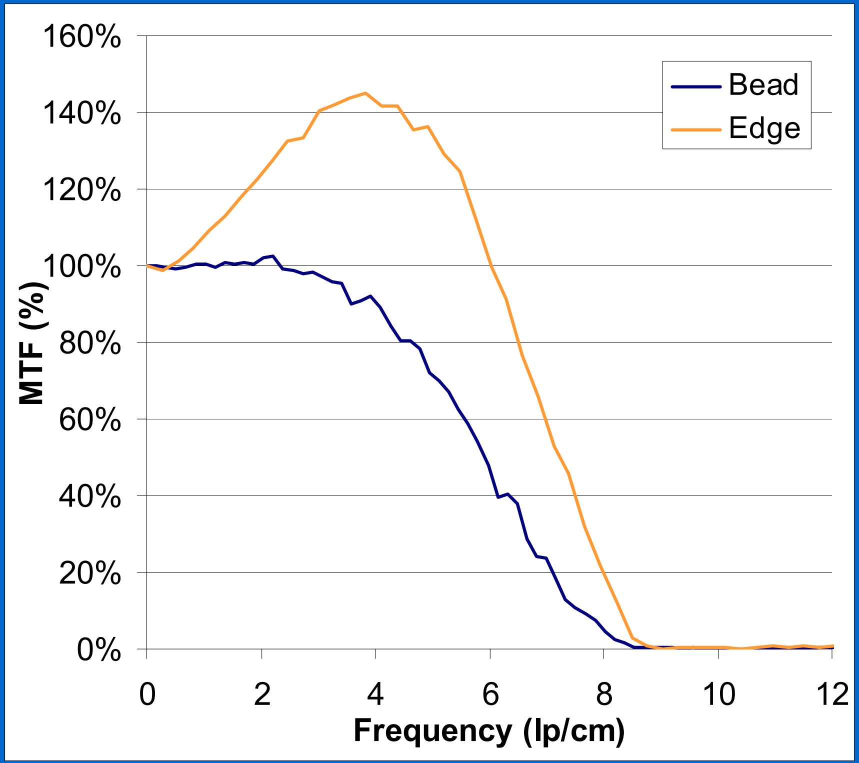




Under/overshoot

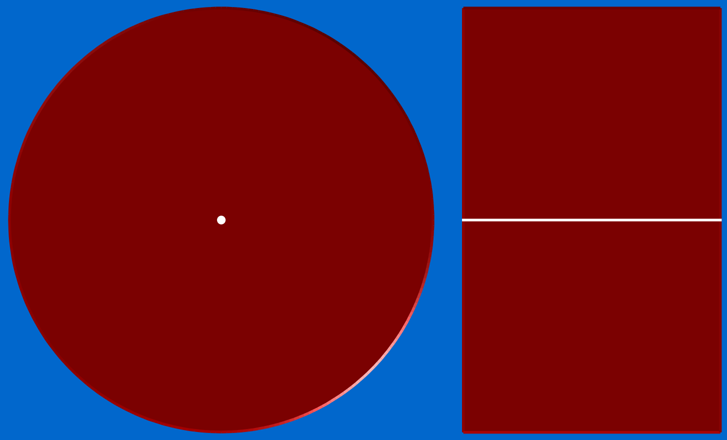
- Undershoot in PSF from ‘edge enhancing’ algorithms different for edge and point methods
  - More undershoot seen in edge PSF → overshoot in MTF
  - Needs further investigation





Conclusions

- An objective method for resolution assessment is essential
- Point techniques seem to produce better results than edge
  - Less noise in MTF
  - Less prone to other problems
- Bead and wires each have their advantages
  - Beads have simpler alignment
  - Wires offer constant contrast
- ImPACT will assess resolution in future with a new 0.1 mm wire phantom (100 mm Ø, 60mm long cylinder, ~60 HU)



Pros and cons of each method

Method	Pros	Cons
Droege and Morin	Can be assessed at console	Poor accuracy
Edge	Multiple images per rotation	Noisy MTF Potential asymmetric ESF Careful alignment required
Bead	Can assess x, y and z resolution. No alignment required	Contrast a function of slice width
Wire	Constant contrast Multiple images per rotation	More careful alignment needed

Correction for finite point size

- Wire and bead methods use a theoretical delta impulse
  - In fact this has a finite size (in our phantoms 0.18 – 0.28 mm)
- Small correction is made to MTF curves due to this
  - $MTF_{measured} = MTF_{system} \times MTF_{point}$
  - Bessel function for a wire, more complicated for bead