The Constant MTF Interpolator: A Resampling Technique with Minimal or No MTF Losses

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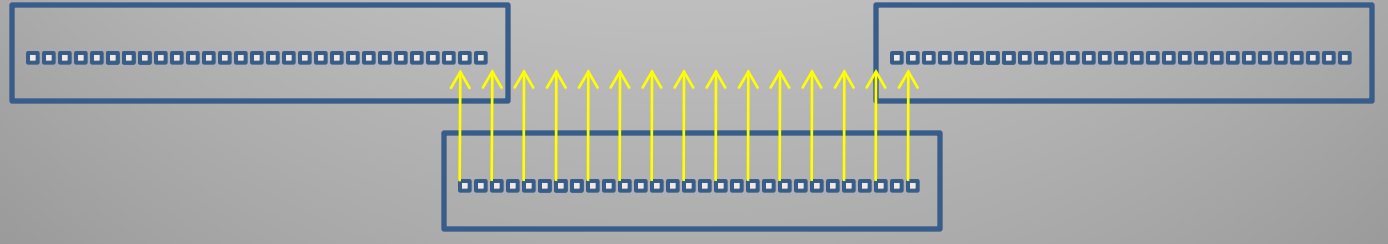
What Is An Image Resampler?

- An algorithm that uses a combination of pixel values to estimate new image values at locations in a grid that do not necessarily correspond to the pixel locations in the original map.
- This often requires an interpolation of values to locations in between the originally spaced pixels.

Use of Resampling Interpolators in Imagery

- Zoom in / zoom out
- Rotation
- Map projections
- Adjusting for sensor chip offsets and misalignments



Form of Interpolators

Interpolators are normally implemented as a convolution kernel that is a function of interpolation (pixel shift) distance

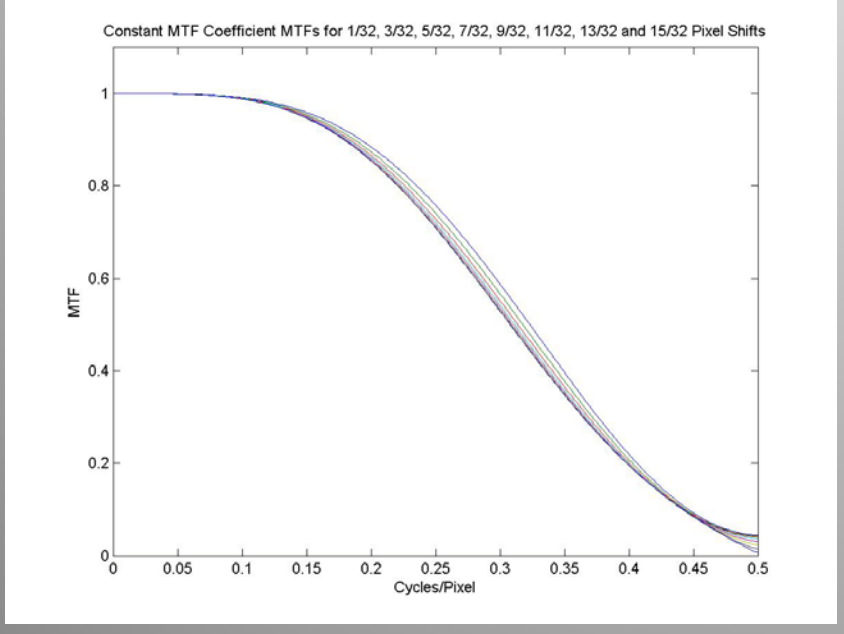
Pixel Shift	Cubic Convolution Coefficients			
1/32	-0.0147	0.9976	0.0175	-0.0005
3/32	-0.0385	0.9793	0.0632	-0.0040
5/32	-0.0556	0.9447	0.1212	-0.0103
7/32	-0.0668	0.8961	0.1894	-0.018
9/32	-0.0726	0.8356	0.2655	-0.0284
11/32	-0.0740	0.7655	0.3473	-0.0388
13/32	-0.0716	0.6880	0.4326	-0.0490
15/32	-0.0661	0.6052	0.5193	-0.0584

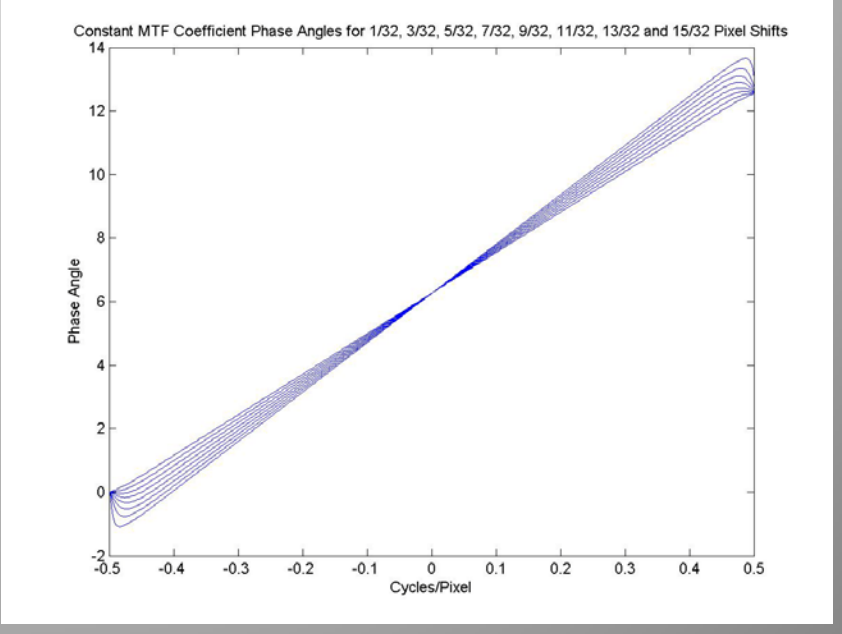
The Problem with Most Interpolators

- All interpolators are low pass filters
  - Interpolators always blur the image and therefore,
    - Reduce interpretability
    - Reduce sharpness
- No interpolator is geometrically perfect
  - There is always a slight difference between the desired and actual pixel shift
- Common interpolators induce a different blur / MTF reduction based upon the degree of pixel shift
  - Creates a different MTF at every point in an image
  - Increases difficulty of estimating MTF from targets in collected images

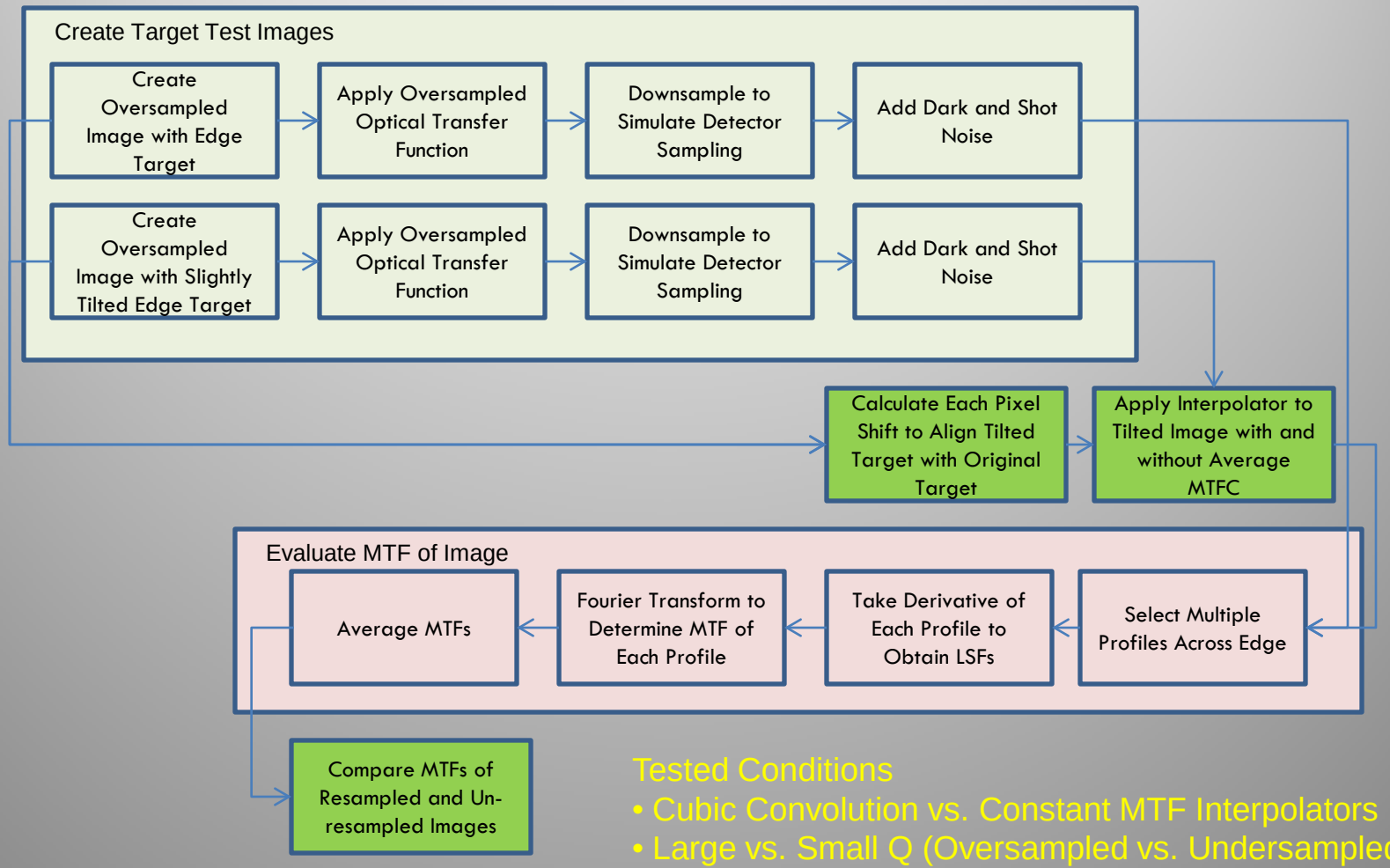
Constant MTF Coefficients Were Developed to Correct the Flaws in Common Interpolators

- Virtually constant MTF across different pixel shift distances
  - Other interpolators impose a different MTF for each interpolation distance
  - Allows one MTFC to be applied to interpolated images and achieve a net unity MTF while correctly shifting pixels
- Highly linear phase (distortionless filter)





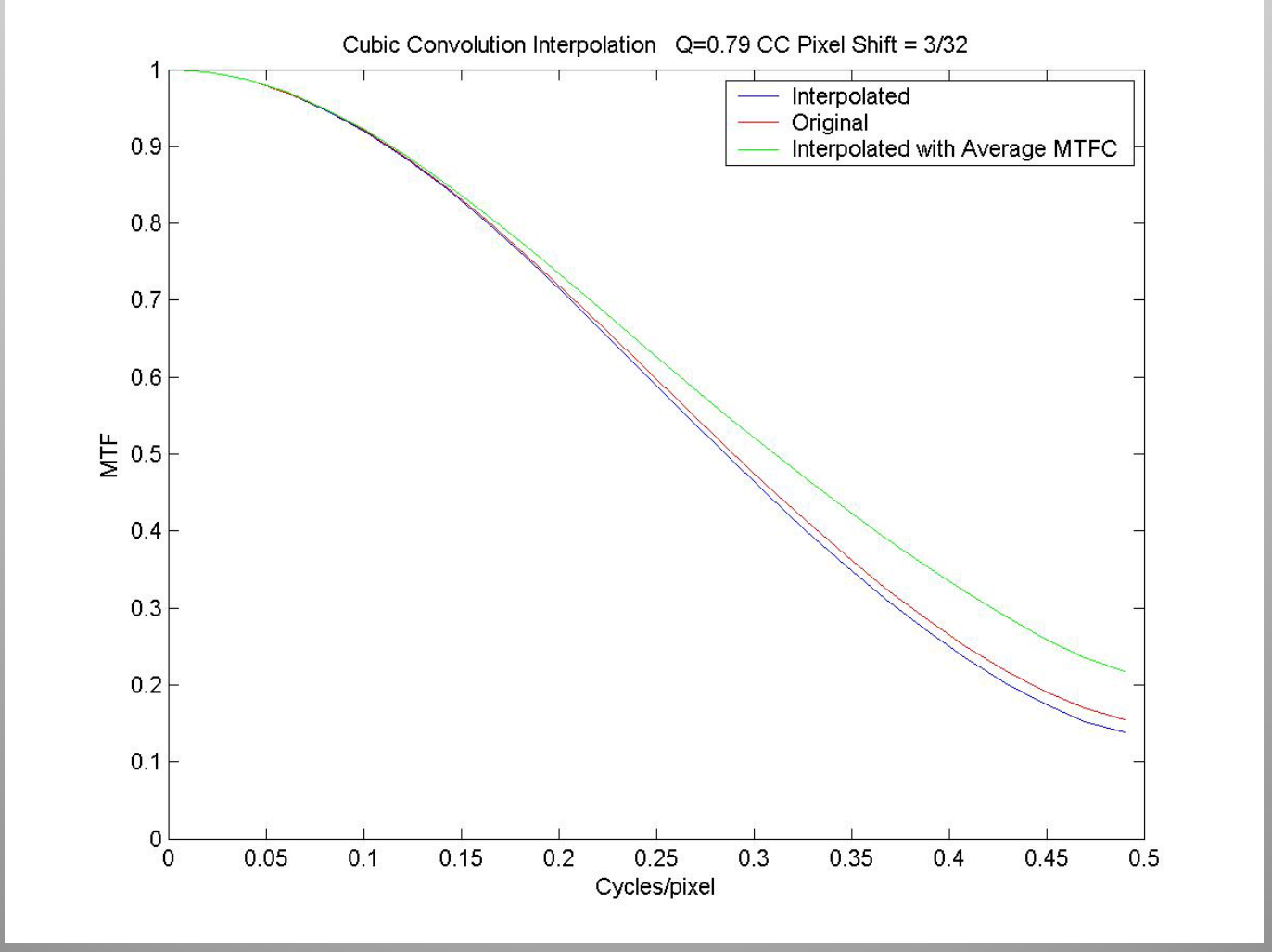
Verification by Analysis and Simulation



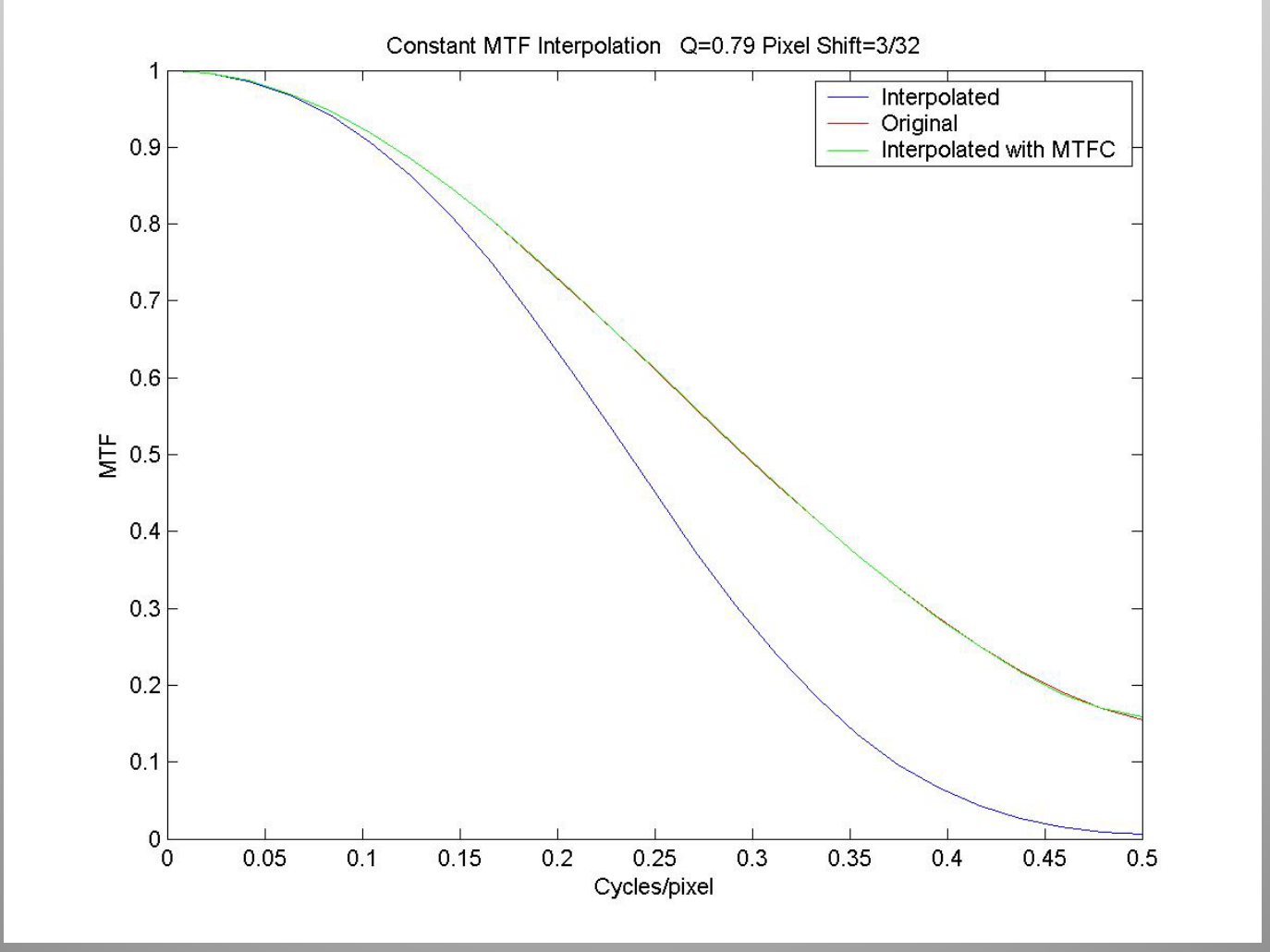
Tested Conditions

- Cubic Convolution vs. Constant MTF Interpolators
- Large vs. Small Q (Oversampled vs. Undersampled)
- Large vs. Small Pixel Shift Distances

Cubic Convolution MTF
Large Q, Small Pixel Shift



Constant MTF Convolution Large Q, Small Pixel Shift



Cubic Convolution MTF
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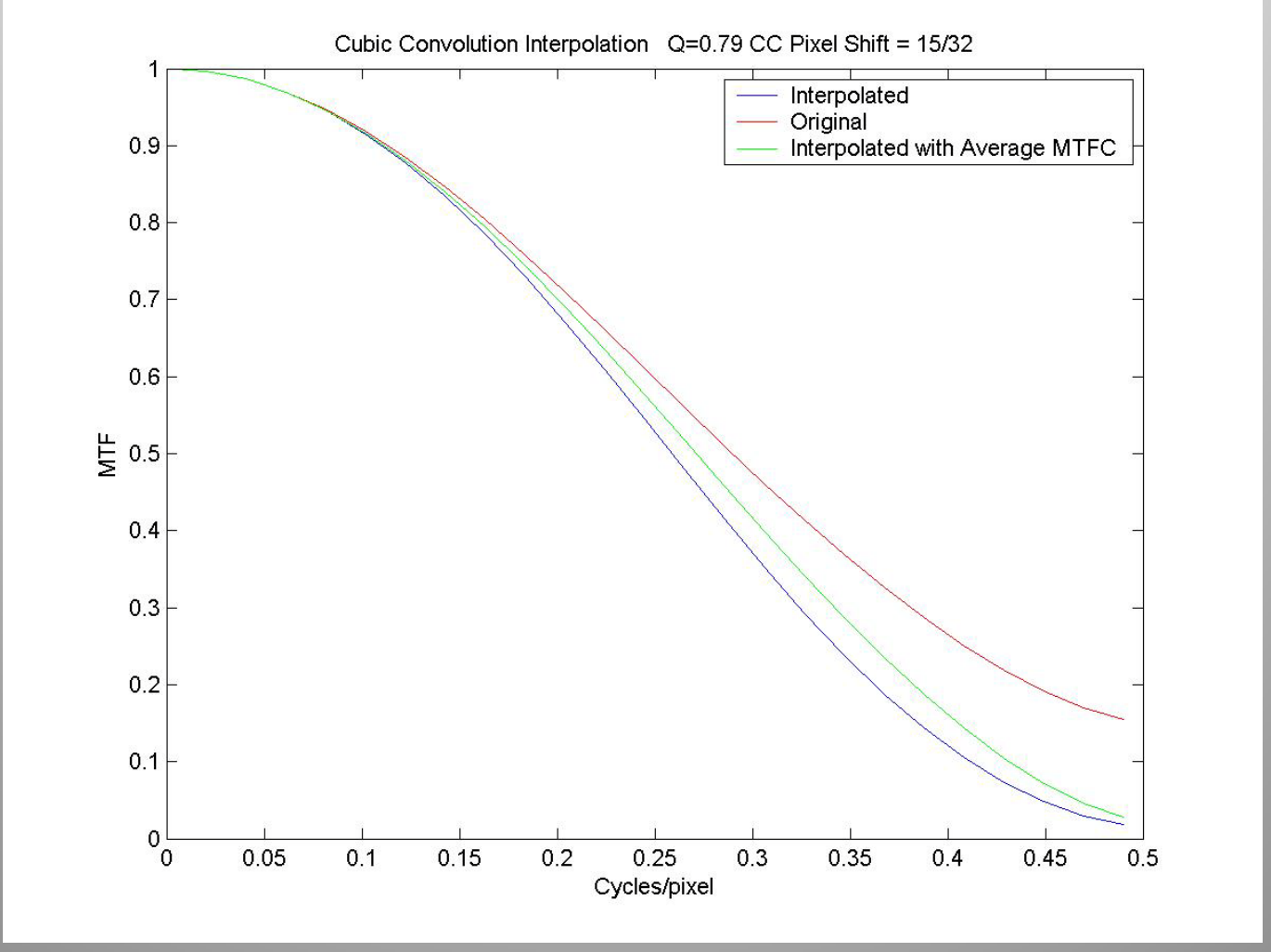
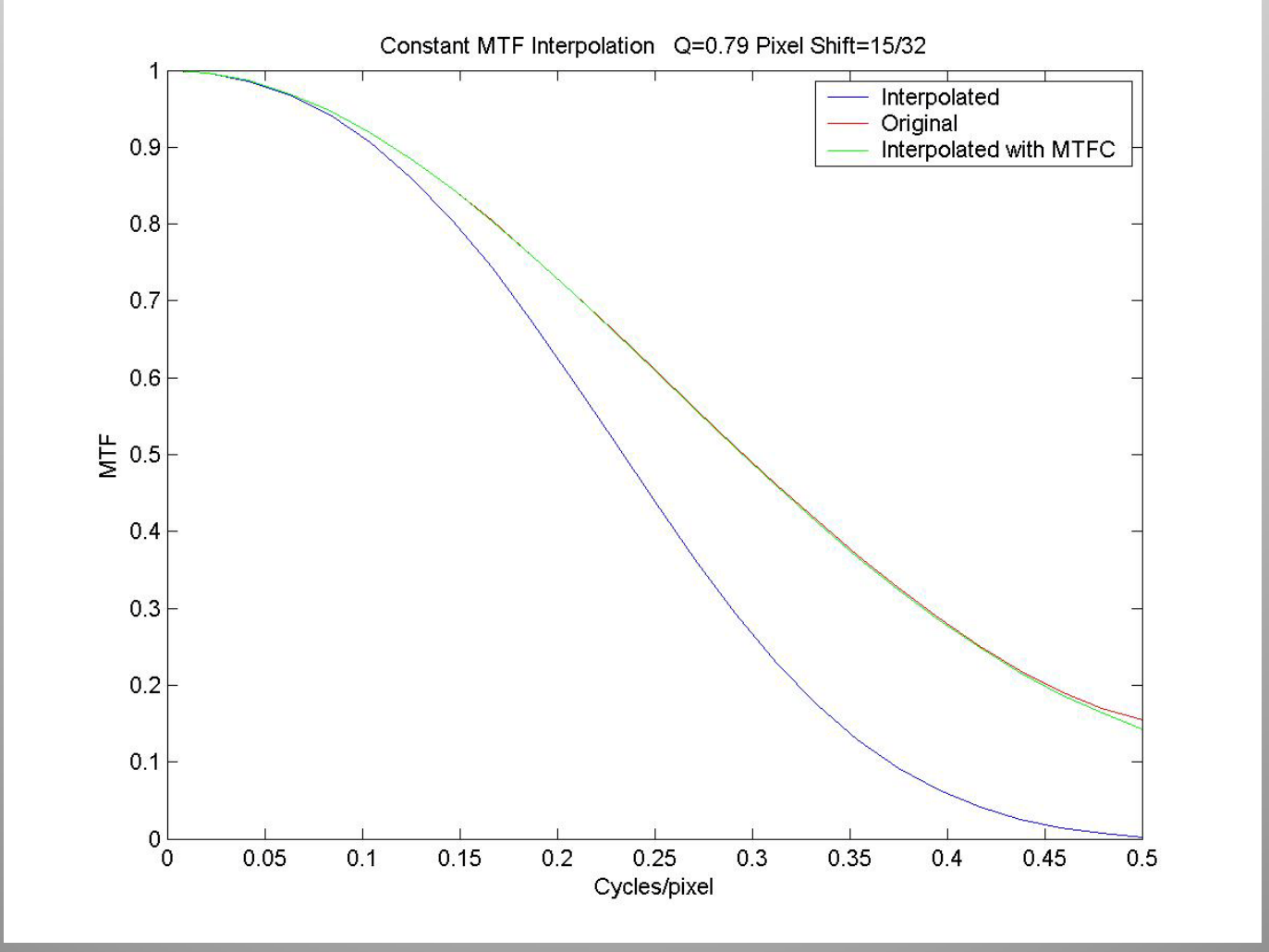
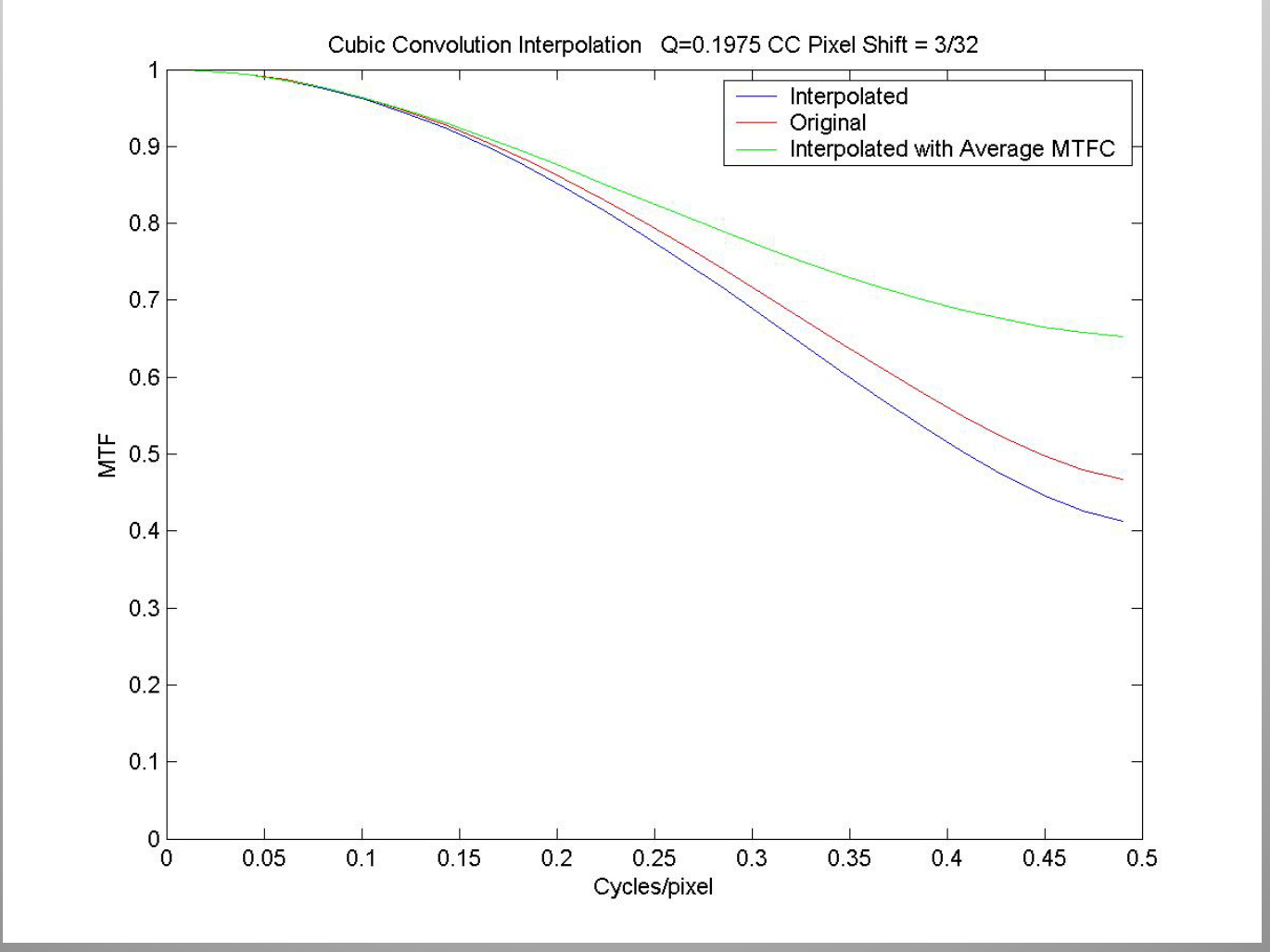


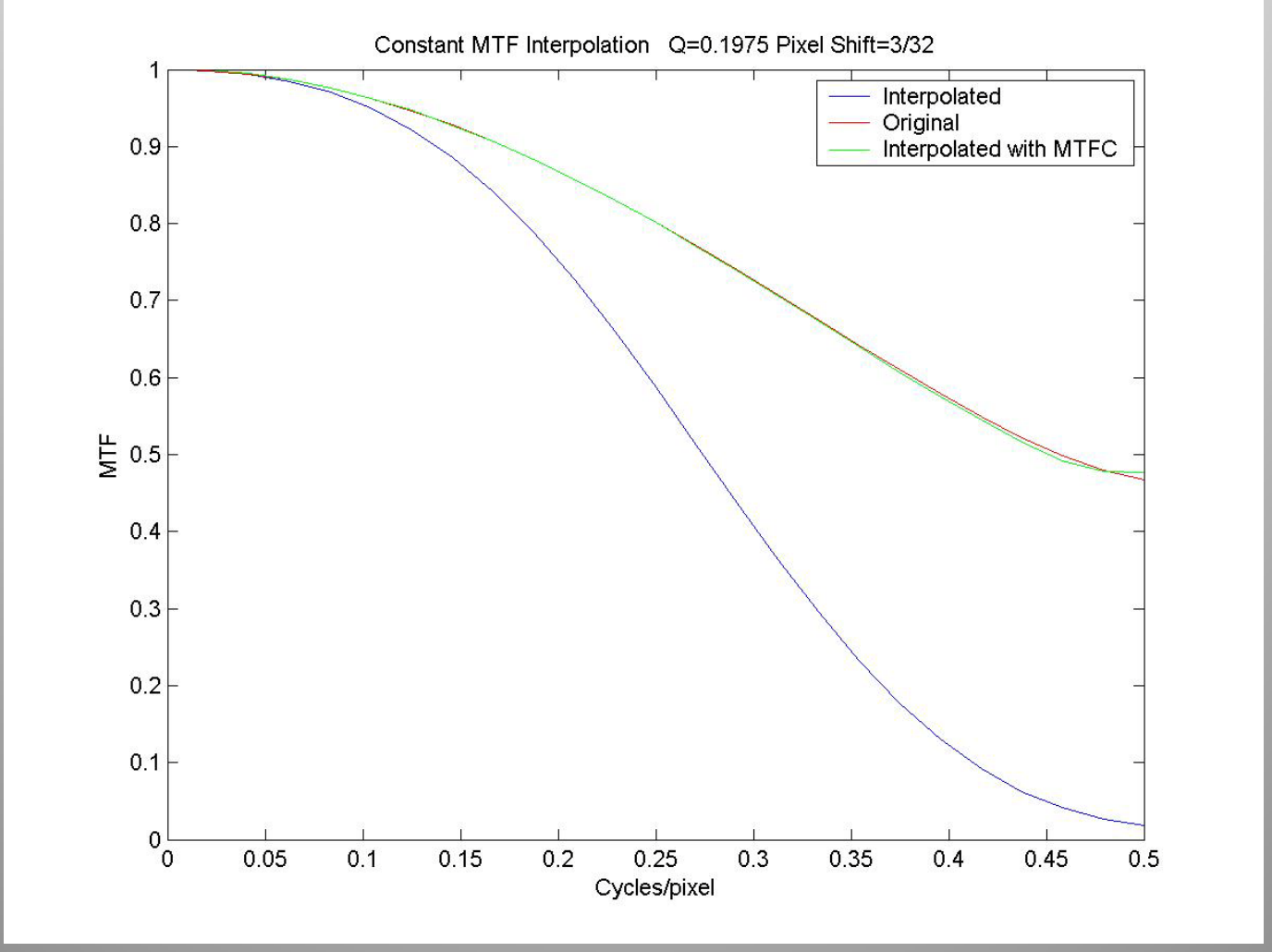
Constant MTF Convolution Large Q, Large Pixel Shift



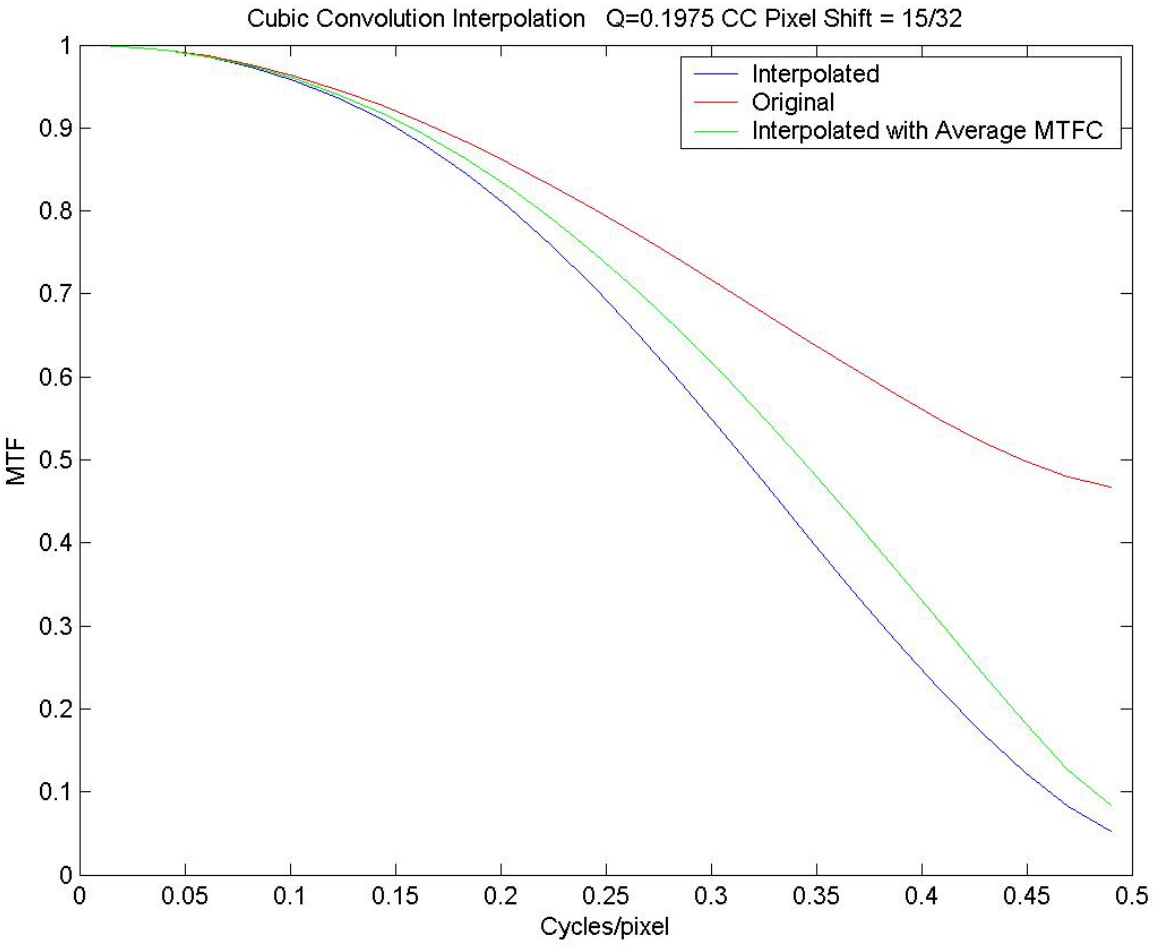
Cubic Convolution MTF
Low Q, Small Pixel Shift



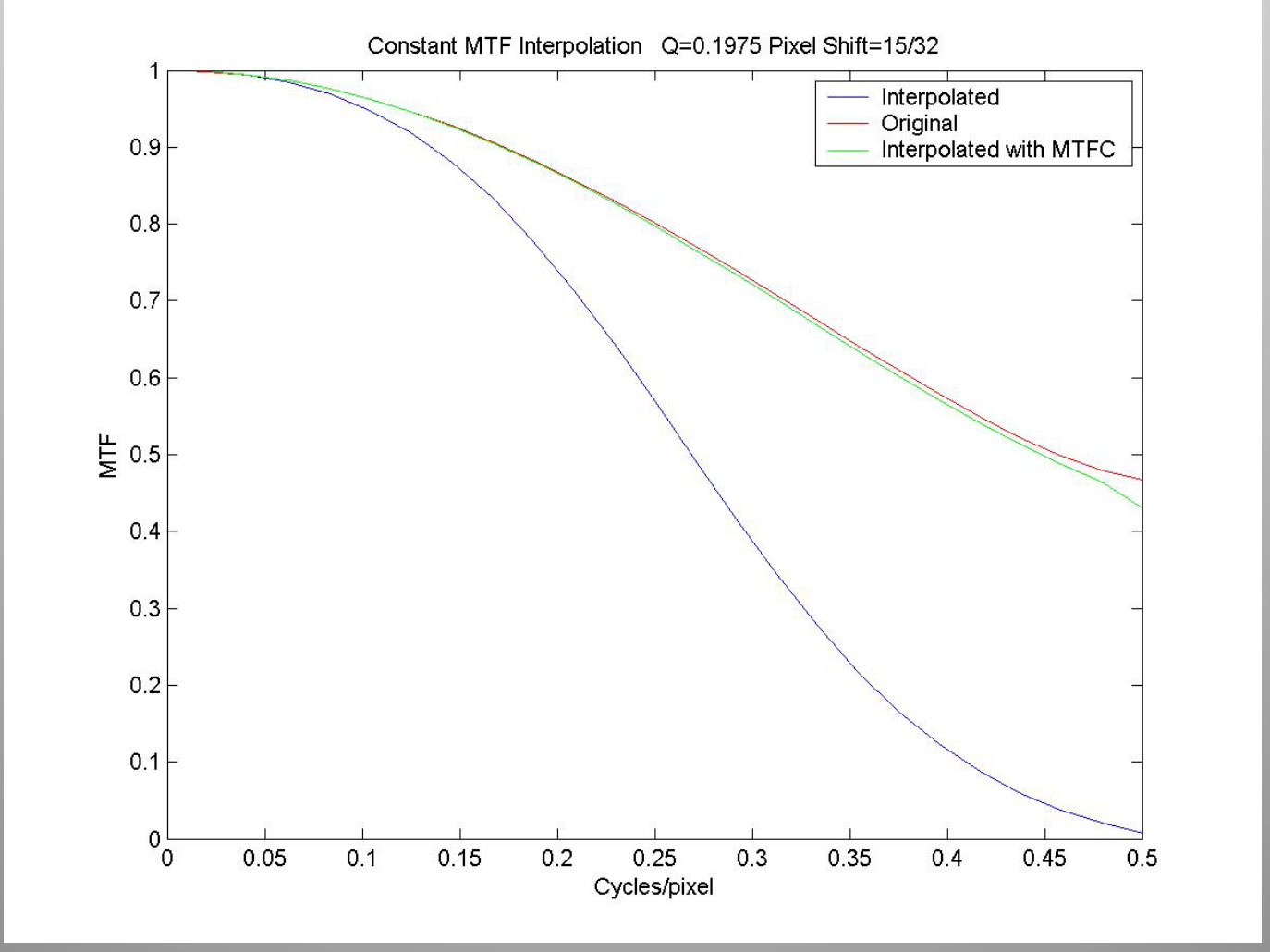
Constant MTF Convolution
Low Q, Small Pixel Shift



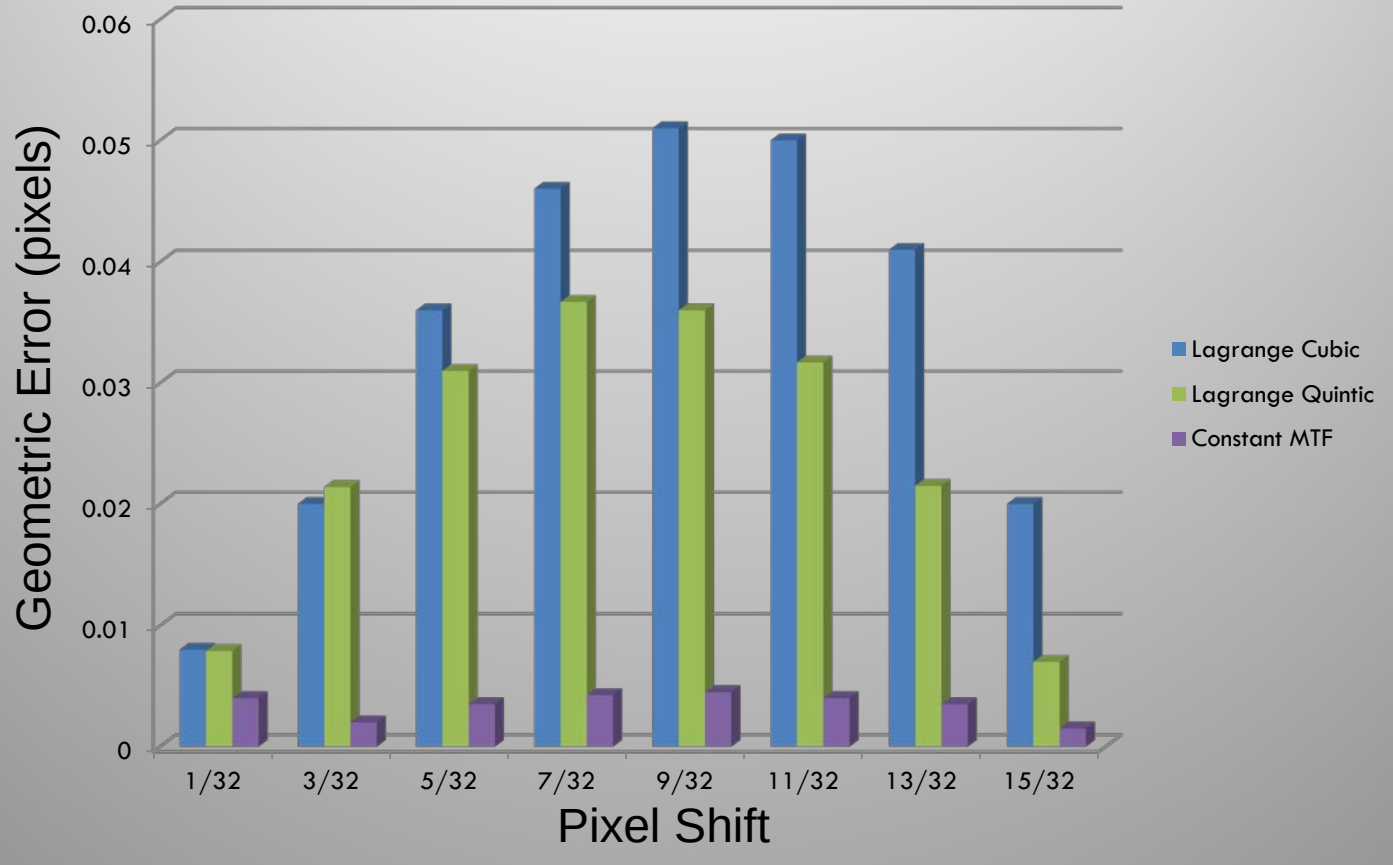
Cubic Convolution MTF
Low Q, Large Pixel Shift



Constant MTF Convolution
Low Q, Large Pixel Shift



Geometric Accuracy of Different Interpolators



NIIRS / Equivalent GSD Improvement Using CMTF Instead of Cubic Interpolation

	Pixel Shift	
Q	**3/32**	**15/32**
0.79	0.05 / 0.97	0.42 / 0.75
0.1975	0.09 / 0.94	0.72 / 0.61

Generalized Image Quality Equation v3

$$NIIRS = 11.81 - 3.32 \cdot \log_{10} GSD + 3.32 \cdot \log_{10} RER - \frac{G}{SNR} - 1.48 \cdot H$$

$$\Delta NIIRS = 3.32 \cdot \log_{10} \left(\frac{RER_1}{RER_2} \right)$$

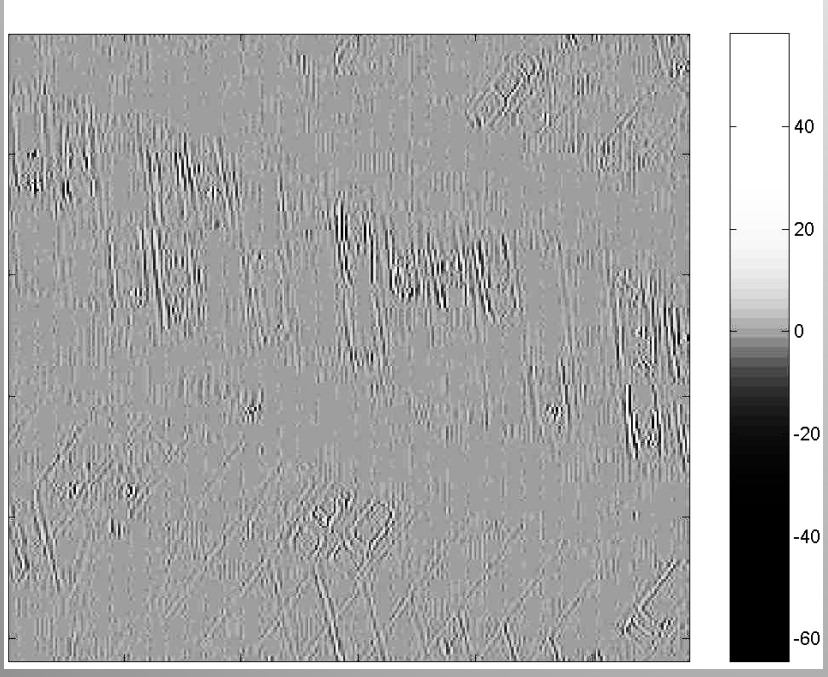
$$\Delta NIIRS = -3.32 \cdot \log_{10} \left(\frac{GSD_1}{GSD_2} \right)$$

Validation with an Image

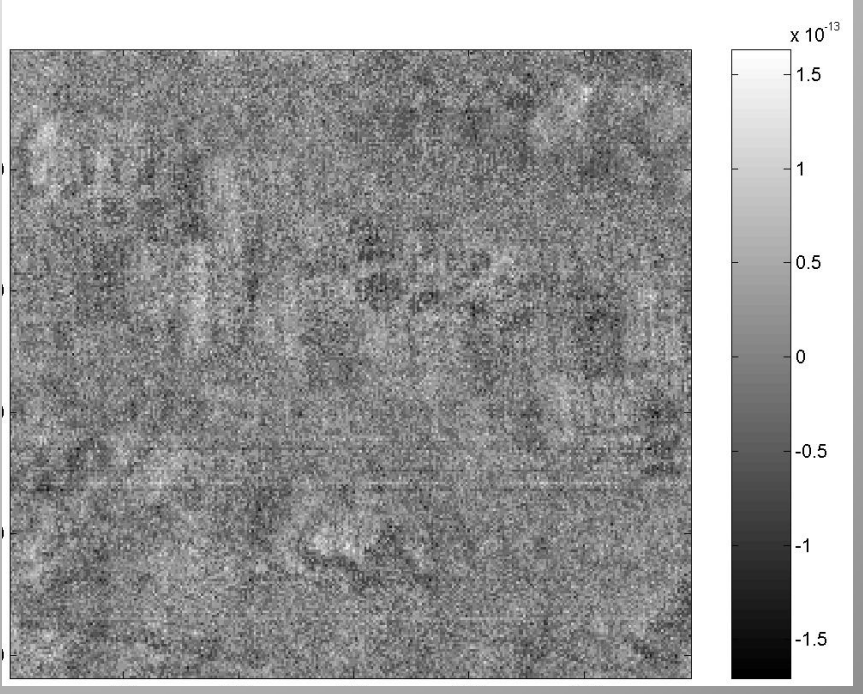
Select an image to be resampled …

Validation with an Image (cont'd)

Resample the image with cubic 15/32 left and right, and subtract the original image.
mean= = 4.9e-4; std dev = 3.4



Resample the image with CMTF 15/32 left and right, and subtract the original image.
mean = 9.4e-17; std dev = 3.7e-14



Residual error in pixel magnitudes after shifting back and forth with cubic interpolator is 14 orders of magnitude larger than with CMTF interpolator and MTFC

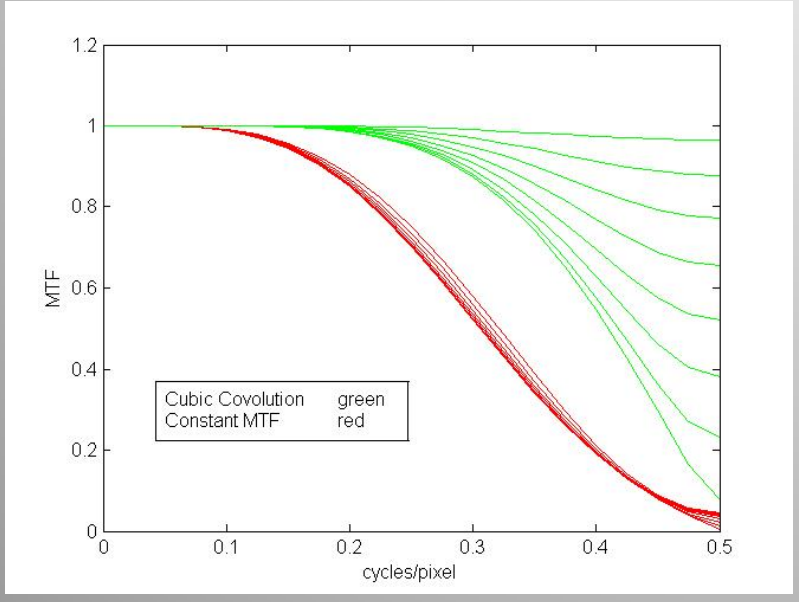
Constant MTF Interpolator Summary

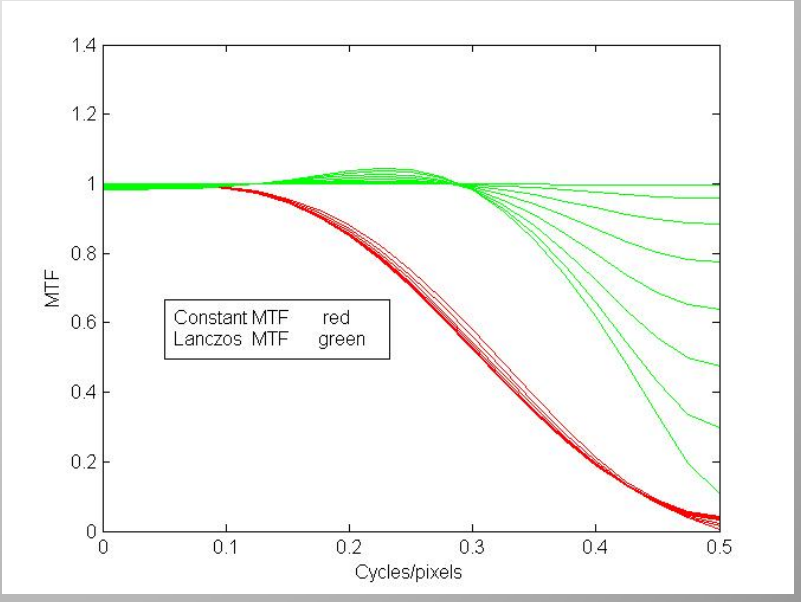
- Can resample an image and be compensated with an MTFC without any significant losses to the image MTF, unlike standard interpolators.
  - Improves image quality
  - Provides better radiometry and spectral exploitation capabilities for small objects and near edges
- Is geometrically more accurate than other interpolators.
  - Slightly improves geolocation accuracy
- May improve pan sharpened products
- Provides significantly better image quality than other interpolators and is not significantly more computationally intensive.

Supplemental Slides

Comparison of MTFs with Constant MTF vs. Cubic and Lanczos Interpolators

Pixel shifts of 1/32, 3/32, 5/32, 7/32, 9/32, 11/32, 13/32 and 15/32

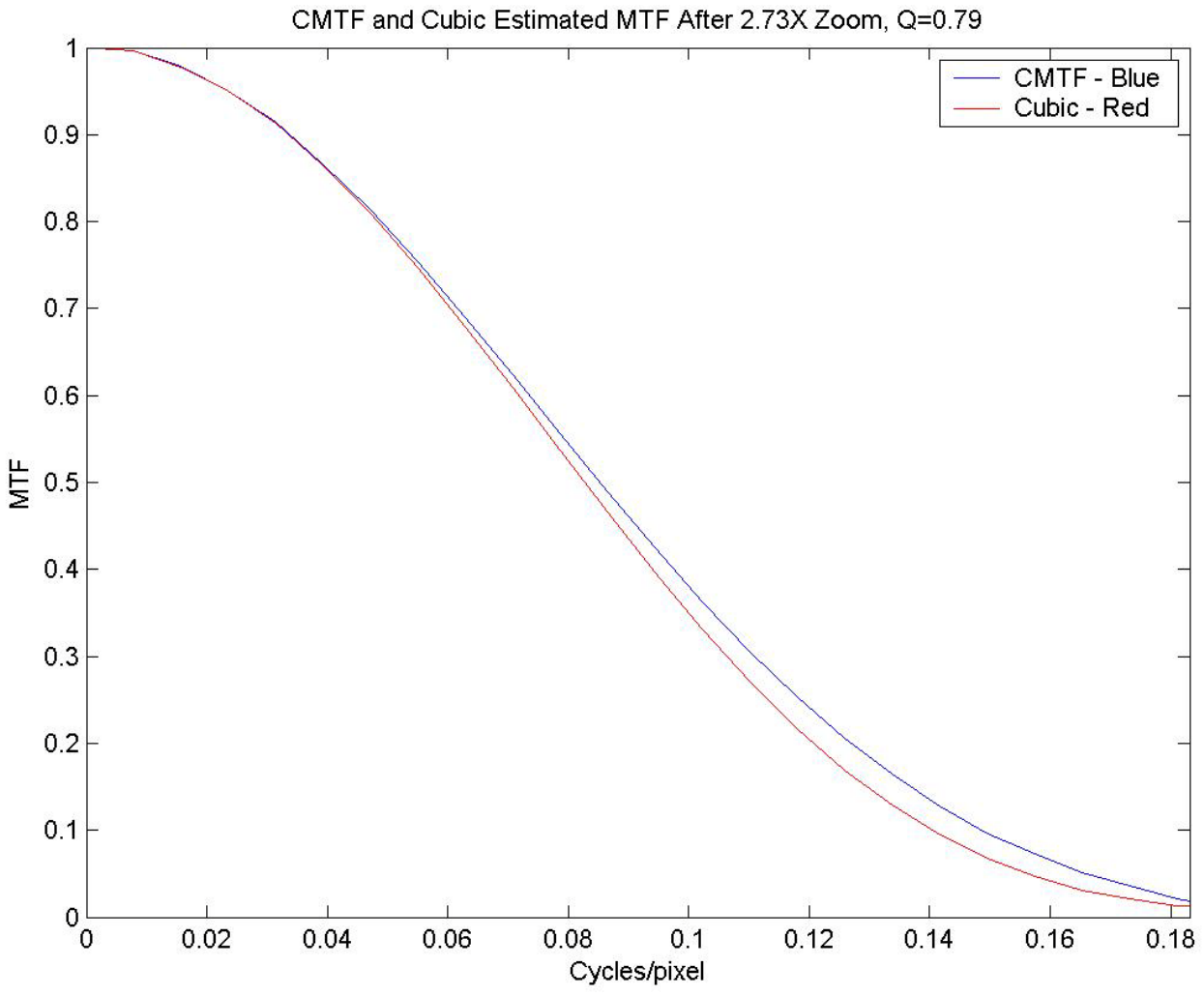




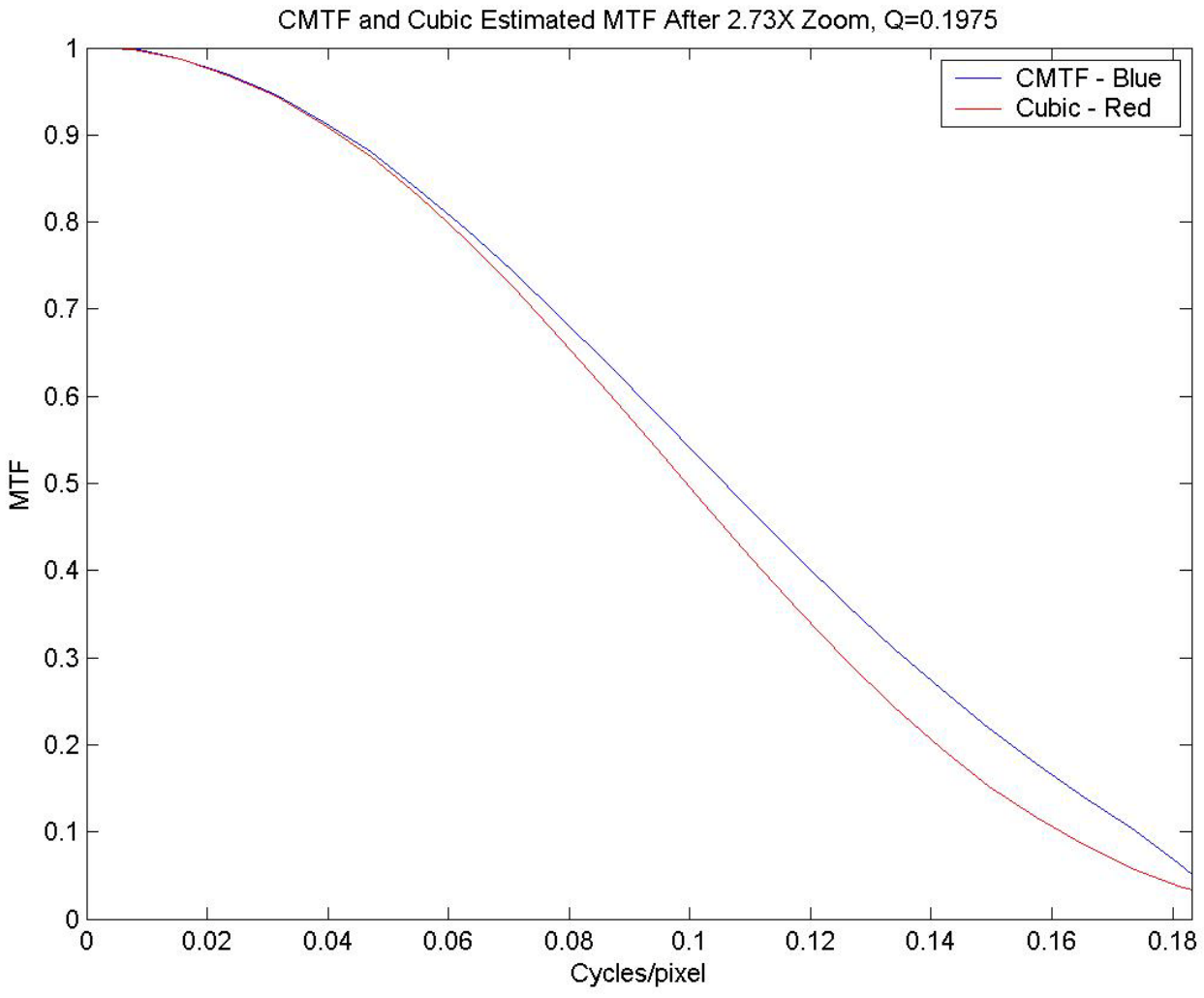
CMTF Can Also Be Used For a Non-Integer Zoom Function

- Performance is better than other interpolators, but not as great as when not zooming
- Oversampling to create more pixels requires low pass filtering to prevent aliasing
  - Filtering out the aliasing also reduces some of the CMTF MTFC compensation
  - Oversampling without filtering induces ringing from the MTFC
- MTF is narrowed proportionally with the zoom factor

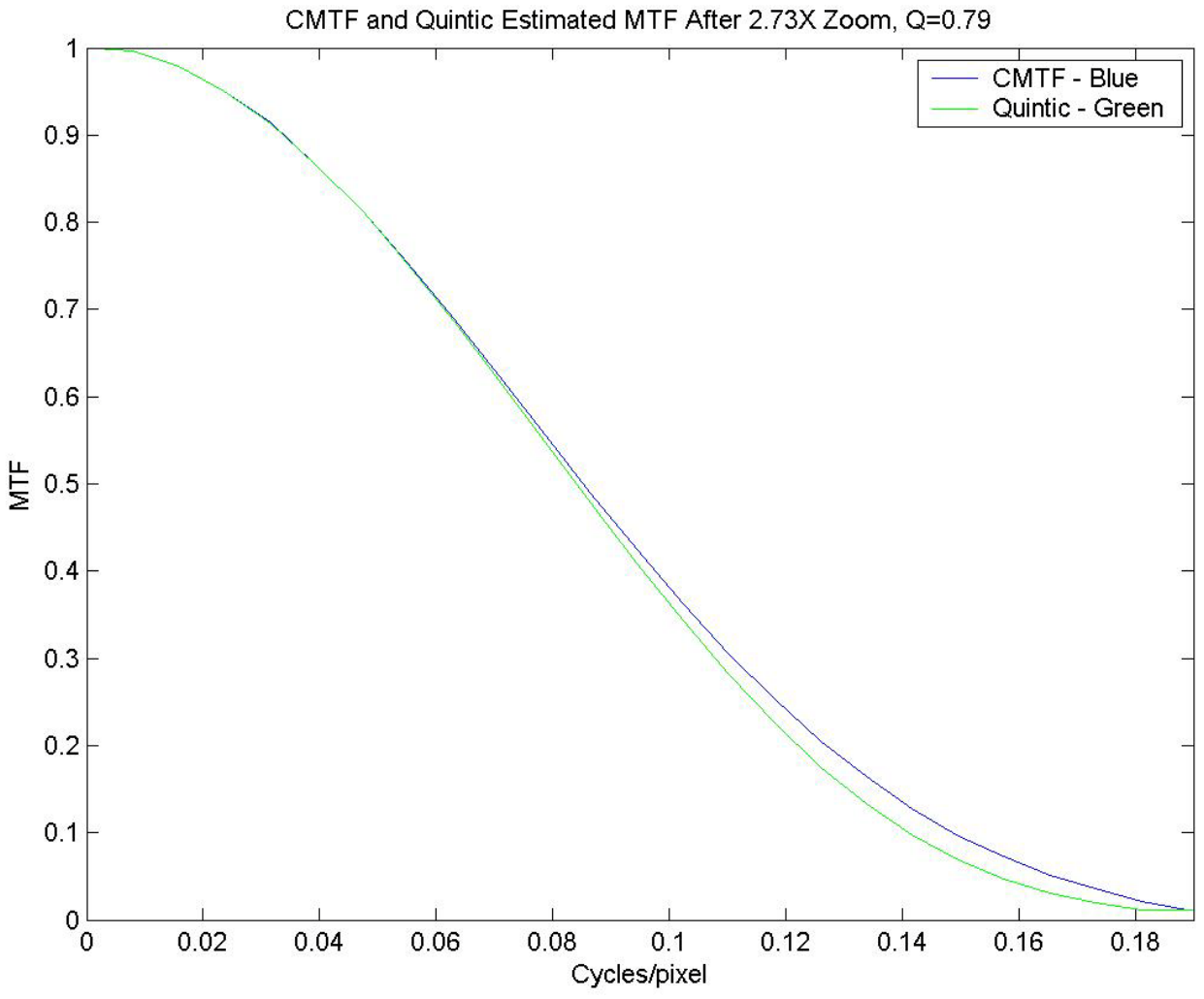
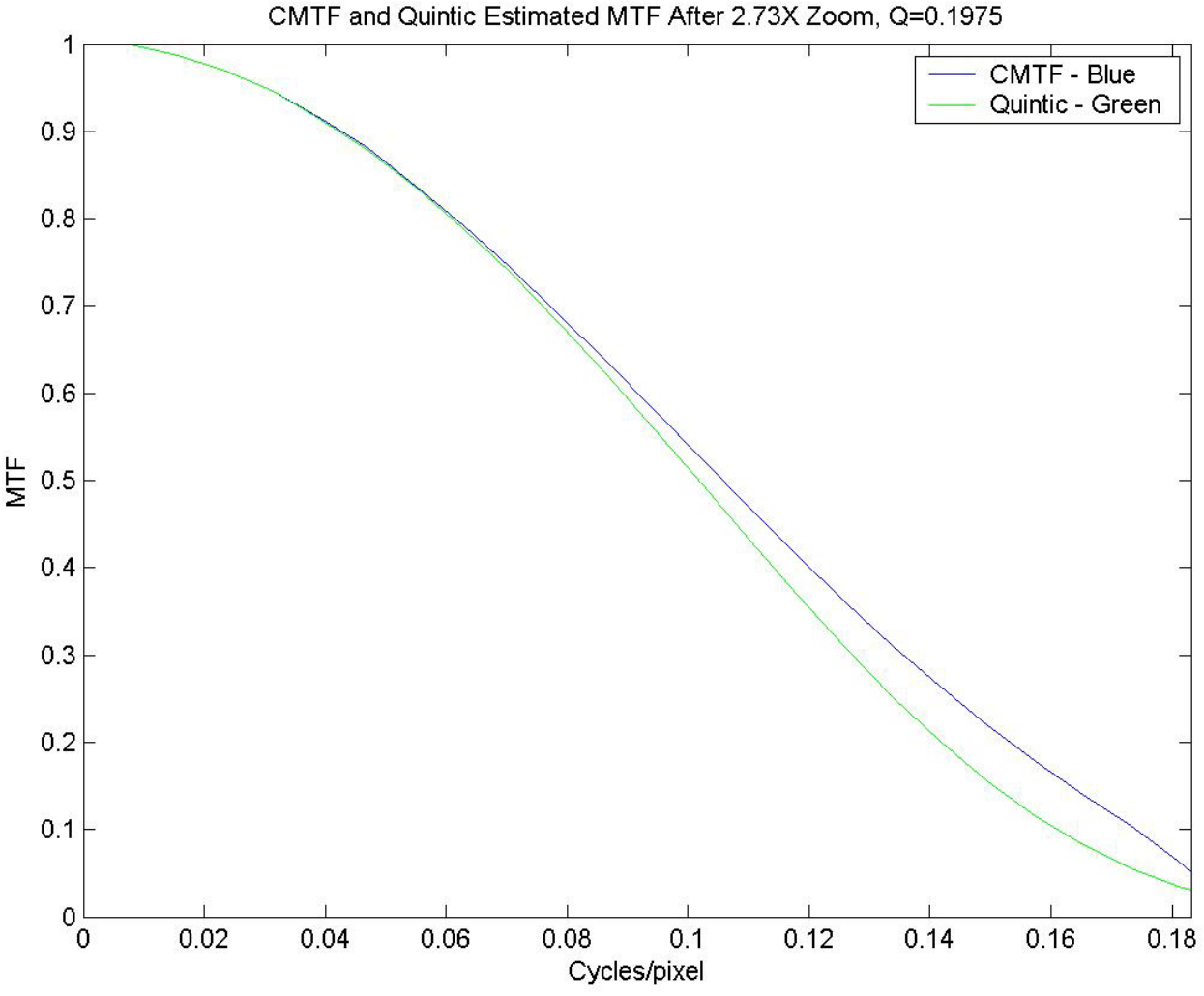
Constant MTF and Cubic Zoom 2.73X, High Q



Constant MTF and Cubic Zoom 2.73X, Low Q



Constant MTF and Quintic Zoom 2.73X, High Q



Constant MTF and Quintic Zoom 2.73X, Low Q