Processing a Bar Target Scan through MITRE's *mtf* Software

Although originally designed to process a scan of a sine wave target, MITRE's *mtf* software can also process a scan of a bar target. When a scanned bar target is input to *mtf*, the output is the "square wave response", also known as the "contrast transfer function" (CTF). If the same imaging system simultaneously scans a bar target and an adjacent sine wave target, the CTF derived from the bar target will not have the same modulation values as the MTF derived from the sine wave target; the CTF has higher modulation values at almost all frequencies. For many purposes, the CTF can be used as is, although it is possible to convert the CTF to its equivalent sine wave MTF (and vice versa). One conversion method uses a straightforward published formula[1], although this method is strictly only valid for a continuous, analog, linear imaging system and an infinite square wave (or sine wave) input. For a discrete-sampled imaging system such as a scanner, a more accurate conversion between MTF and CTF is obtained via a more involved procedure, which considers the MTF in conjunction with the bar target's Fourier spectrum and sampling pixel convolution[2].

For accurate CTF assessment of a sampled imaging system using *mtf*, the bar target should contain enough parallel bars at each frequency such that: the optimum phase between scanner sensor array and target bars will be captured, aliasing will be detected (if present), and the computed CTF will accurately represent the system. A good rule of thumb is given in the following table. The bar target should also contain at least one relatively large bar or square, of a size equivalent to ≤ 3% of the Nyquist frequency of the imaging system; this low frequency component is used for normalization of the CTF computed by *mtf*.

Bar Target Frequency	**Minimum Number of Parallel Bars**
≤ 3% of Nyquist	1
> 3% to 10% of Nyquist	4
> 10% to 40% of Nyquist	5
> 40% of Nyquist	10

Notes: Bar length should be at least 10 times bar width.
Width of space between parallel bars equals bar width.

[1] "The Specification of Imaging Properties by Response to a Sine Wave Target", J. W. Coltman, June, 1954, Journal of the Optical Society of America, Vol. 44, No. 6, pp. 468-471.

[2] "Conversion Between Sine Wave and Square Wave Spatial Frequency Response of an Imaging System", N. B. Nill, MITRE Corporation Technical Report MTR-01B021, July, 2001.

PROCEDURE

Target Data File:

The bar target data file format is substantially the same way as for a sinewave target data file[3], with some differences: Since a bar target usually does not contain a step tablet there is no data in the bar target data file representing target gray patches. However, if the imaging device input/output relation is nonlinear, that relation is appended to the end of the data file (after last frequency component information) and it will be taken into account in the *mtf* processing (as of *mtf* v6.2)[4]. The following example illustrates the data file setup, showing just the last, highest frequency bar pattern information in the file followed by a few of the nonlinear input/output data pairs (input might be reflectance, output is always image gray level):

```
11        # label
b         # signifies bar pattern (would be ‘s’ for sinewave)
16.183    # UL pattern corner in mm from left edge of target
4.038     # UL pattern corner in mm from top edge of target
1.45      # pattern width in mm
0.5       # pattern height in mm
1.        # target modulation
10.       # frequency in cycles/mm


0.0    0.0     #InputValue  OutputGray
0.1    5.0
0.16   10.0
.
.
0.83   248.0
1.0    255.0
```

The “target modulation” entry in the bar target data file can be set equal to 1.0 if it is not known, a priori. The real bar target modulation would then be taken into account by dividing the CTF output of *mtf* by the separately computed modulation of a very low frequency target bar. Alternatively, one can independently measure the 0 frequency modulation in the image before running *mtf,* then input that modulation as “target modulation” in the datafile, then the *mtf* output is the CTF, with no further normalization. [If the device has a nonlinear response then the 0 frequency modulation needs to be computed in input (target) space by backtracking the 0 frequency bar and surrounding space image gray levels through the nonlinear curve and then computing modulation.]

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[3] For sinewave data file format, see: “Computer Program to Determine the Sine Wave Modulation Transfer Function (MTF) of Imaging Devices”, N. B. Nill, D. J. Braunegg, B. R. Paine, MITRE Corporation Technical Report MTR-96B025, November 1996, Appendix C.

[4] When using a sine wave target the step tablet values representing the input/output relation are at the beginning of the data file and must be present, even if device has a linear response; whereas the input/output relation need not be included in the data file for a bar target, if device response is linear.

Example:

As an example of computing the CTF from a bar target scan, consider the 15-bar target, sometimes called a “T-90” target. This target covers an area of approximately 17 x 17 mm, the length of a given bar is 10 times the bar‘s width, and spatial frequencies start at 1.0 cy/mm, increasing in a 10th root of 10 progression. Figure 1 shows this target with two added low frequency blocks (0.3 cy/mm).

The first part of the target data file for the vertical bars is given below. The basic rule in constructing the data file is that the bars must be vertical, the origin for measurements is always the upper left corner of the target, and measurements are in units of millimeters. When a bar target has bars in only one direction, as in Figure 1, then only one data file need be constructed, regardless of the imaged orientation of the target (*mtf* asks the user for image quadrant orientation, and then makes the proper orientation corrections)[5].

If the bar target contains both vertical and horizontal bars, then a separate data file must be constructed for each bar orientation. The vertical bar data file is constructed as given in the previous paragraph. To construct the horizontal bar data file, the target is first rotated 90 degrees clockwise so the bars appear as vertical, then the origin for measurement is again in upper left corner of the rotated target. Note that we are talking about target orientations for constructing the target data file needed for input to *mtf*; the target can be imaged in any quadrant orientation.

In the following data file snippet, the # symbol signifies comments, which can take up to 80 columns per line, or they can appear after a data entry (+ space) on the same line. The ## are comments that would be picked up by *mtf* for runtime display.

Other *mtf* Input Parameters:

3 Corner Points: The 3 corner points are corners of a rectangular area that contains the target analysis area. Some targets will have visible features that can be precisely located at each corner. When this occurs the pixel positions of these features in the scanned target (taken from the image display) should be input to *mtf*. If the corner locations are not immediately visible: first display the image, then draw horizontal and vertical lines around the perimeter of the target, such that a given line coincides with the outer edge of the outermost bar along that side of the target, as illustrated in Figure 2 (these reference lines do Not become part of the image to be processed through *mtf*).

Target Orientation: To compute the CTF, the target reference data must be correctly rotated to allow alignment with the scanned image. The orientation is entered manually as 0, 9, -9, or 1 indicating a rotation of 0, 90, -90 or 180 degrees. When processing a portion of the image that contains vertical bars (horizontal processing), the appropriate answer is either 0 or 1. When processing a portion of the image with horizontal bars (vertical processing), the appropriate answer is either 9 or -9. Figures 3-5 show examples of how different target representations should (and shouldn’t) be rotated to align with the scanned image. [Brighter colors than the default are used for visibility in this documentation.] Use the debug image to check that the chosen orientation is correct.

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[5] More exactly, to run MITRE’s *mtf* program, a bar target must be imaged in an orientation such that the bars are perpendicular or parallel to sensor rows or columns.

Input Data File Snippet:

```
# 15-bar target, 10th root of 10 frequency progression
## TgtDataFile for target bars that are VERTICAL when target is UPRIGHT

345-T90   # target serial number

12        # total number of bar patterns

17.7      # target width in mm
17.1      # target height in mm

# Bar Patterns Follow:
1       # label
b       # signifies bar pattern
0.      # UL pattern corner in mm from left edge of target
0.      # UL pattern corner in mm from top edge of target
14.5    # pattern width in mm
5.      # pattern height in mm
1.      # target modulation
1.      # frequency in cycles/mm

2           # label
b           # signifies bar pattern
0           # UL pattern corner in mm from left edge of target
6           # UL pattern corner in mm from top edge of target
11.518      # pattern width in mm
3.972       # pattern height in mm
1           # target modulation
1.25893     # frequency in cycles/mm

3           # label
b           # signifies bar pattern
0           # UL pattern corner in mm from left edge of target
10.972      # UL pattern corner in mm from top edge of target
9.149       # pattern width in mm
3.155       # pattern height in mm
1           # target modulation
1.58489     # frequency in cycles/mm

4           # label
b           # signifies bar pattern
0           # UL pattern corner in mm from left edge of target
15.127      # UL pattern corner in mm from top edge of target
7.267       # pattern width in mm
2.506       # pattern height in mm
1           # target modulation
1.99526     # frequency in cycles/mm
```

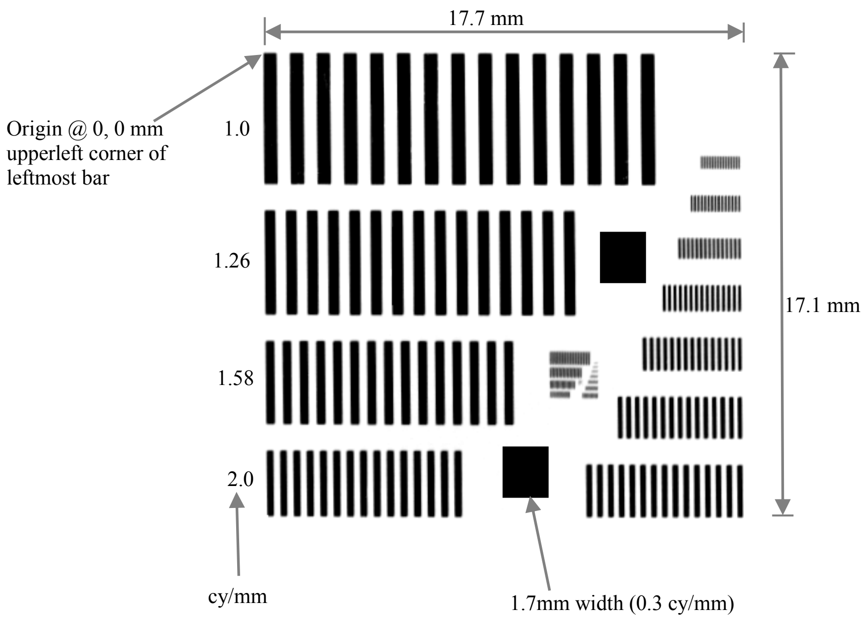


Figure 1. Example 15-Bar Target with Low Frequency Blocks, in Upright Orientation Used to Construct Data File for Vertical Bars

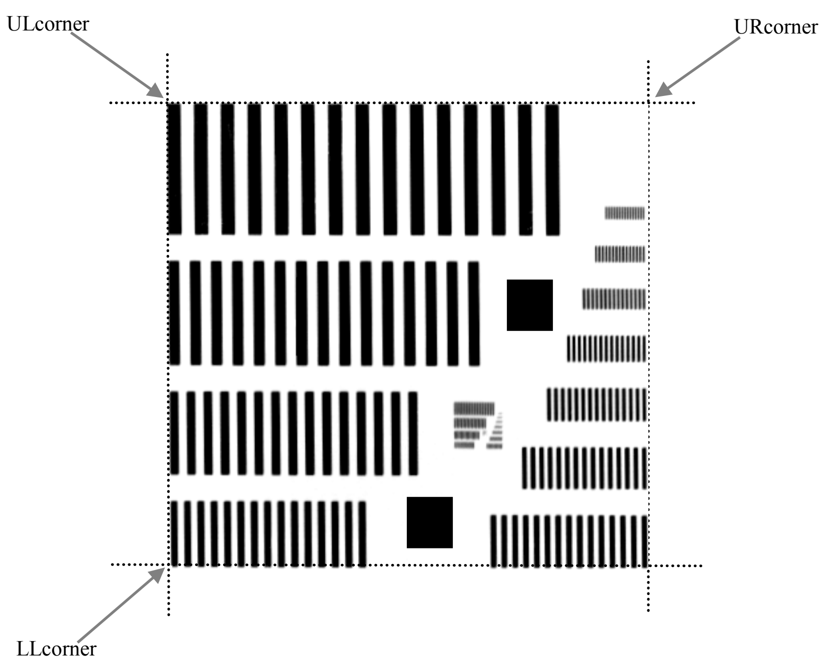
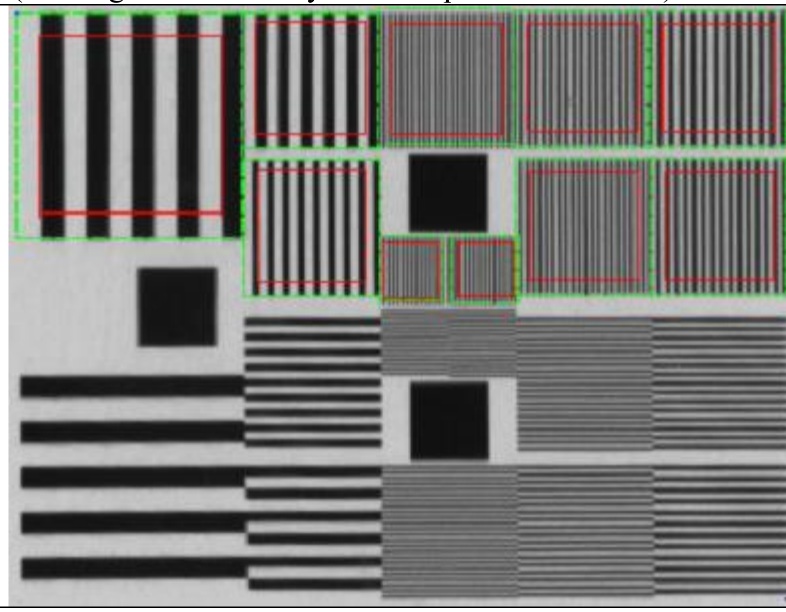


Figure 2. Image Corner Coordinate Locations for Input to *mtf*; Dotted Frameline Temporarily Added to Displayed Image, to Establish the Row, Column Pixel Locations of the Imaged Target Corners.

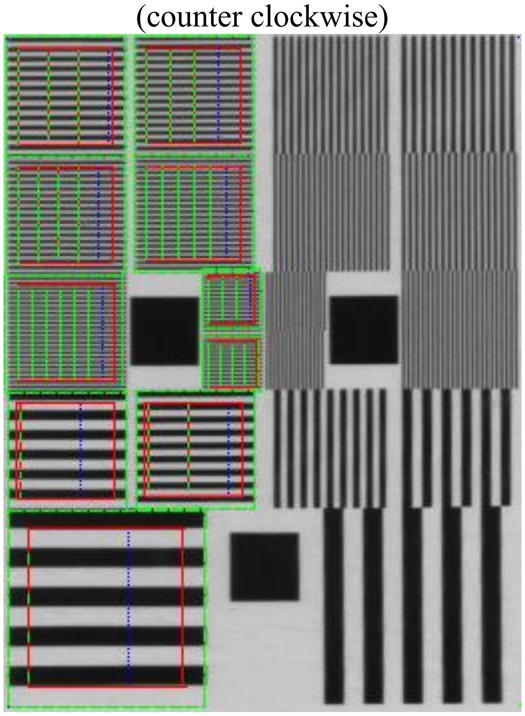
Target Reference File #1 (full target area but only outlined patterns included)

Full Target 19 mm x 13 mm
1 cy/mm pattern offset (0,0)



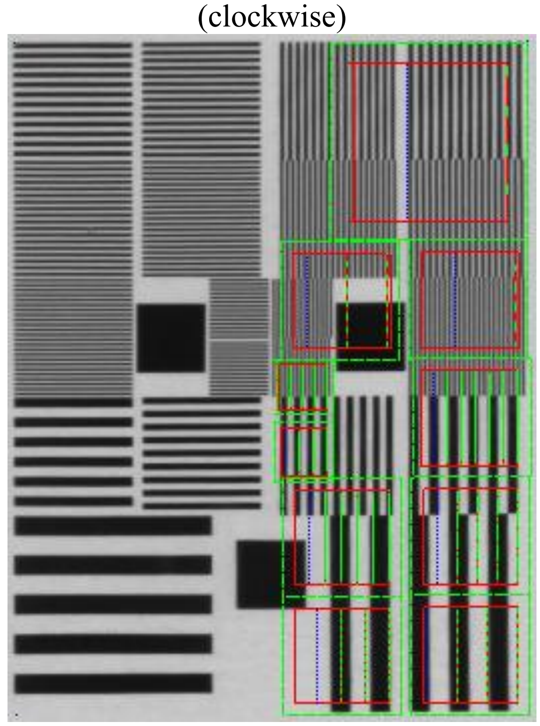
Diagnostic Image after running mtf on a Particular Image

Reference rotated -90 degrees
(counter clockwise)



Correct alignment

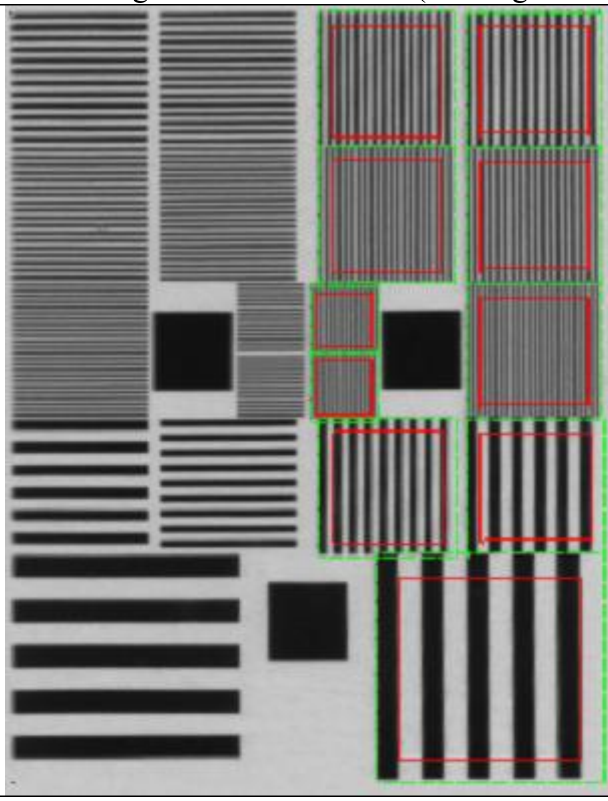
Reference rotated 90 degrees
(clockwise)



Incorrect alignment

Figure 3. Target Rotation for Input to *mtf*;
(top) Target A Area as Represented in Target Reference File,
(bottom) Alignment produced by -90 and 90 degree rotations

Target Reference File #2 (full target area but only outlined patterns included)



Full target 13 mm x 19 mm
1 cy/mm pattern offset at (8,12)

Diagnostic Image after running mtf on a Particular Image

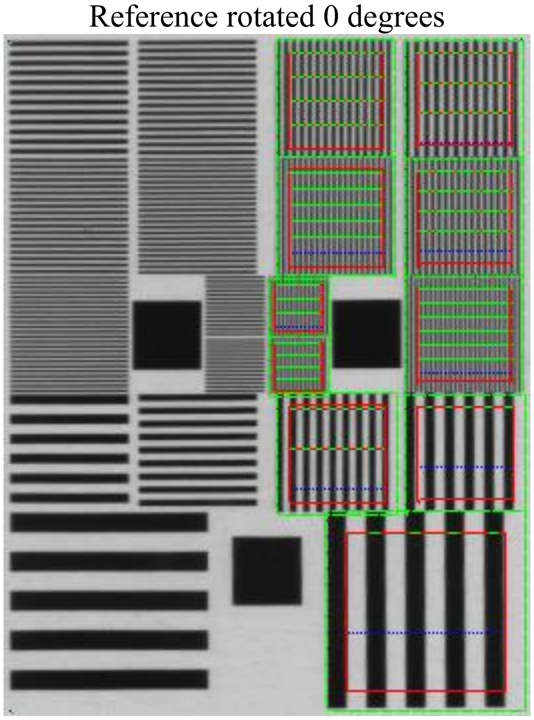
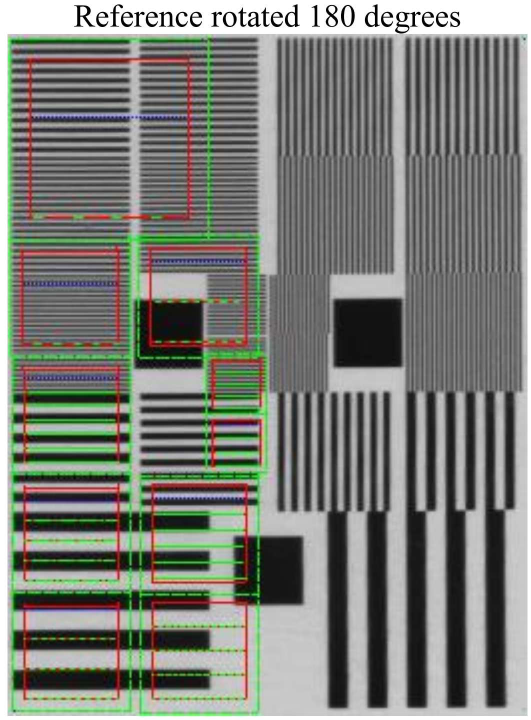
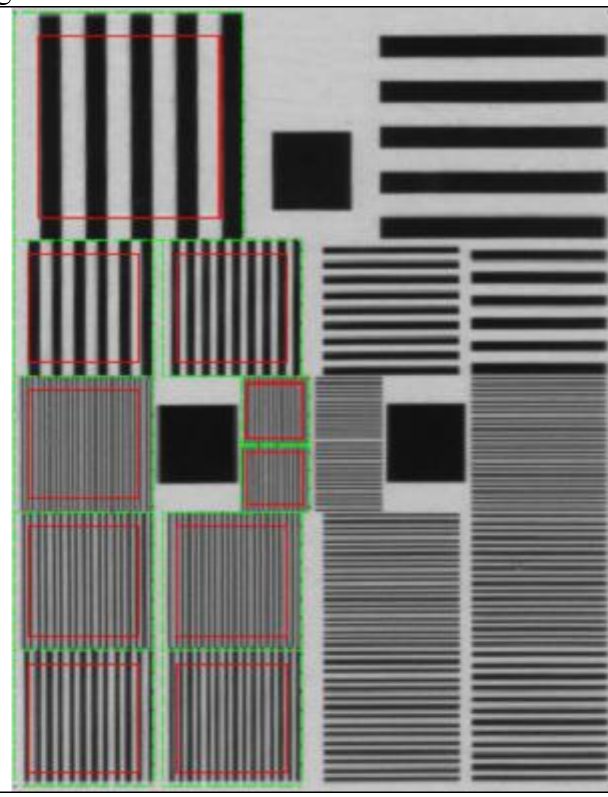
Reference rotated 0 degrees	Reference rotated 180 degrees
	
Correct alignment	Incorrect alignment

Figure 4. (top) Target B Area as Represented in Target Reference File, (bottom) Alignment produced by 0 and 180 degree rotations

Alternate Target Reference File #2

Full target 13mm x 19mm
1 cy/mm pattern offset at <u>(0, 0)</u>



Diagnostic Image after running mtf on a Particular Image

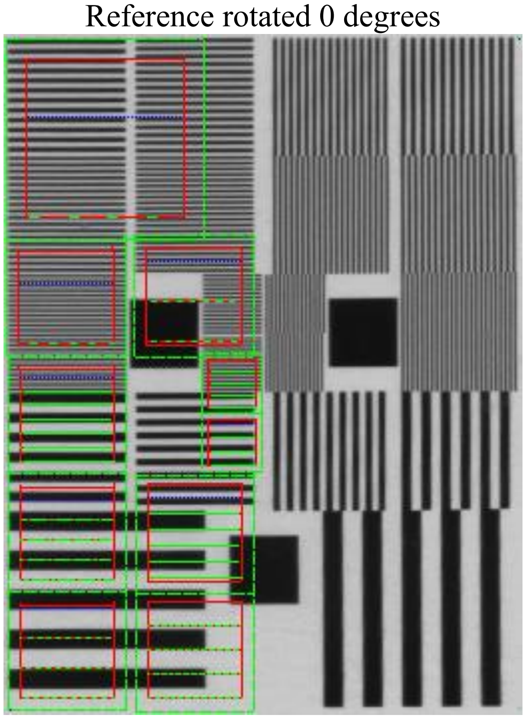
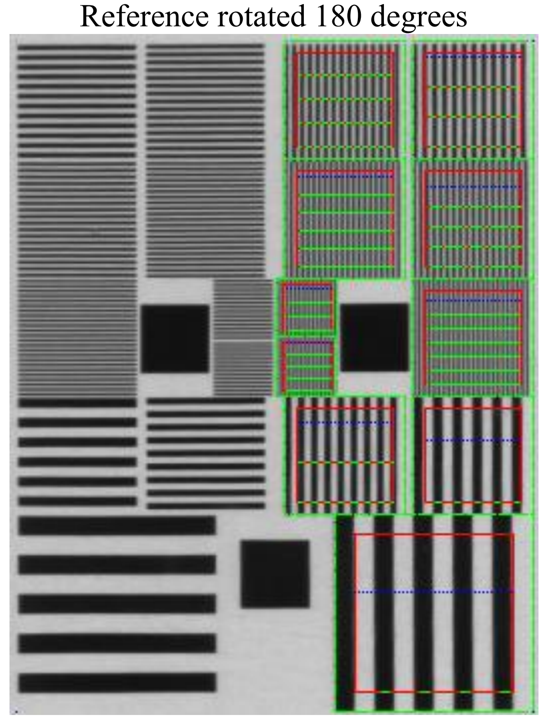
Reference rotated 0 degrees	Reference rotated 180 degrees
	
Incorrect alignment	**Correct alignment**

Figure 5. (top) Alternate Representation of Target B Area in Target Reference File, (bottom) Alignment produced by 0 and 180 degree rotations