efg's Computer Lab Image Processing

Tech Note

USAF 1951 and Microcopy Resolution Test Charts and Pixel Profiles

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USAF 1951 3-Bar Resolving Power Test Chart

Military Standard

From MIL-STD-150A, Section 5.1.1.7, *Resolving Power Target*:

"The resolving power target used on all tests shall be as follows: The target shall consist of a series of patterns decreasing in size as the $\sqrt{2}$, $\sqrt[3]{2}$, $\sqrt[6]{2}$, with a range sufficient to cover the requirements of the lens-film combination under test. The standard target element shall consist of two patterns (two sets of lines) at right angles to each other. Each pattern shall consist of three lines separated by spaces of equal width. Each line shall be five times as long as it is wide." (See Figure 1)

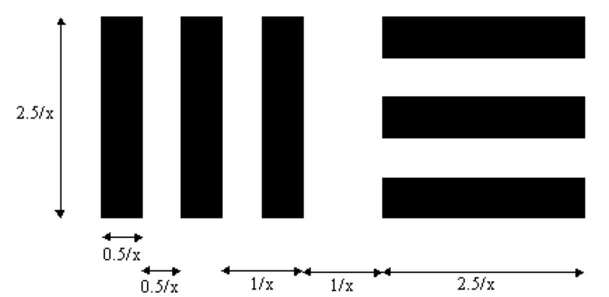


Figure 1. Standard Resolving Power Test Target Element.
From MIL-STD-150A: *"The patterns of lines are parallel lines 2.5 x millimeters long and 0.5 x millimeters wide with space 0.5 x millimeters wide between the parallel lines, where x equals the number of lines per millimeter."*

"The target contrast (the difference in photographic density between the lines and spaces) shall be either high, medium, or low contrast, as specified."

"*High contrast target.* A high contrast target is one in which the density difference between the light and dark areas is greater than 2.00."

"*Medium contrast target.* A medium contrast target is one in which the density difference between the light and dark areas is equal to 0.80 ± 0.05."

"*Low contrast target.* A low contrast target is one in which the density difference between the light and dark areas is equal to 0.20 ± 0.05."

The combination of a single black bar and a single white bar, with combined size 1/x as shown in Figure 1, is known as a cycle. Resolutions are often specified in cycles/millimeter. Since one cycle contains a single (black) line, lines per millimeter and cycles per millimeter are numerically the same.

Selwyn's "Rule of Thumb"

MIL-STD-150A, Section 5.1.2.12, *Resolving Power* quotes a "rule of thumb" by Selwyn that the numerical value of the magnification should approximately equal the number of lines resolved per millimeter. (Based on Selwyn's experiments from National Bureau of Standards C526, 219, 1954 and *Photographic Journal 88B*, 46, 1948). This is a useful approximation for determining what test target should be resolved for a given magnification.

USAF 1951 3-Bar Resolving Power Test Chart

This test target shows several groups of test target elements, which conform to MIL-STD-150A. Each group consists of six elements, which are progressively smaller. The elements within a group are numbered from 1 to 6. Odd-numbered groups appear contiguously, 1 through 6, at the upper right corner. The first element of even-numbered groups is at the lower right, with the remaining five elements, 2 through 6, at the left. Each even-odd pair make up a layer, with the next smaller even-odd pair near the center. See Figure 2.

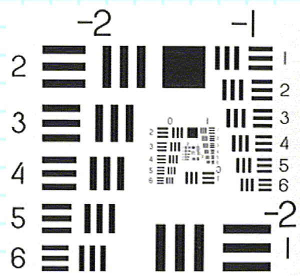


Figure 2. USAF 1951 Test Target.

(Test Target T20 from Applied Image, Rochester, NY)

Per MIL-STD-150A, the size of each target element within a group is progressively smaller. Table 1 shows the scaling factors for the elements of a group given the size of the first element:

Element of Group	Factor (mathematical)	Factor (numerical)
1	2^{0}	1.00000
2	$2^{-1/6}$	0.89090
3	$2^{-2/6}=\frac{1}{\sqrt[3]{2}}$	0.79370
4	$2^{-3/6}=\frac{1}{\sqrt{2}}$	0.70711
5	$2^{-4/6}$	0.62996
6	$2^{-5/6}$	0.56123

Table 1. Scaling Factor for Each Element Within a Group.

For the Applied Image T20 Target, The starting point of the largest group (labeled "-2") is a test target element with lines that are 10 mm long. The 1st element of the "-2" group is at the lower right of the test target with the labels "-2" and "1". The elements 2 through 6 of this group are at the far left. The lengths of the lines of the various elements in the "-2" group are in Table 2 (using the factors from Table 1 and rounding to the nearest 0.01 mm):

Element of "-2" Group	Line Length [mm]
1	10.00
2	8.91
3	7.94
4	7.07
5	6.30
6	5.61

Table 2. Size of Elements in "-2" Group.

The largest element of the second group (labeled "-1" and "1") is at the upper right corner. This first element of the "-1" group is half the size of the first element of the "-2" group. As you can see from the table above, *Scaling Factor for Each Element Within a Group*, the factor for a seventh element in a group would have been 0.5 if one existed. So, mathematically the first element of a group continues the same progression from the last element of the previous group.

The group number gives the power of 2 that is the "x" value in the MIL-STD-150A Figure caption shown above. This figure caption indicates lines are *2.5/x* mm long. So for the "-2" group, we have

$$\frac{2.5\text{ mm}}{x} = 10\text{ mm} = \frac{2.5\text{ mm}}{2^{-2}}$$

Or, $x = 2^{-2} = 0.25$, which means there are 0.25 lines resolved per mm. Table 3 summarizes the test target group "-2" to "5":

Group	Line Length of First Element of Group [mm]	Lines Resolved Per Millimeter $x = 2^{Group}$
-2	10.000	0.25
-1	5.0000	0.50
0	2.5000	1
1	1.2500	2
2	0.62500	4
3	0.31250	8
4	0.15625	16
5	0.078125	32

Table 3. USAF 1951 Test Target Group Summary.

A general formula for the length or width of any target element line can be expressed as the following:

$$\text{Line Length[mm]} = \frac{2.5\ \text{mm}}{2^{\text{Group}+(\text{Element}-1)/6}}$$

Since, Line Width[mm] = Line Length[mm] / 5, the following expression holds:

$$\text{Line Width [mm]} = \frac{1}{2^{\text{Group}+1+(\text{Element}-1)/6}}$$

Table 4 shows the length in millimeters of target element lines for the various groups:

	Element					
Group	**1**	**2**	**3**	**4**	**5**	**6**
-2	10.00000	8.90899	7.93701	7.07107	6.29961	5.61231
-1	5.00000	4.45449	3.96850	3.53553	3.14980	2.80616
0	2.50000	2.22725	1.98425	1.76777	1.57490	1.40308
1	1.25000	1.11362	0.99213	0.88388	0.78745	0.70154
2	0.62500	0.55681	0.49606	0.44194	0.39373	0.35077
3	0.31250	0.27841	0.24803	0.22097	0.19686	0.17538
4	0.15625	0.13920	0.12402	0.11049	0.09843	0.08769

Table 4. Line Length[mm] as Function of Group Index and Element Index.

Let's reconsider Selwyn's "rule of thumb" that says the numerical value of the magnification should approximately equal the number of lines resolved per millimeter. From above, the lines resolved per millimeter is "x," which can be expressed:

$$x = 2^{\text{Group}+(\text{Element}-1)/6}$$

and

Magnification » x

From this information, we can construct Table 5 that shows the approximate magnification needed to resolve a particular test target group element:

	Element

Group	1	2	3	4	5	6
-2	0.3	0.3	0.3	0.4	0.4	0.4
-1	0.5	0.6	0.6	0.7	0.8	0.9
0	1.0	1.1	1.3	1.4	1.6	1.8
1	2.0	2.2	2.5	2.8	3.2	3.6
2	4.0	4.5	5.0	5.7	6.3	7.1
3	8.0	9.0	10.1	11.3	12.7	14.3
4	16.0	18.0	20.2	22.6	25.4	28.5

Table 5.
Approximate Magnification Needed to Resolve USAF Test Target Elements
Based on Selwyn's "Rule of Thumb."

Values in the above table that are less than 1.0 indicate a "macroscopic" view, i.e., no magnification is needed to resolve the target elements.

Microcopy Resolution Test Chart (NBS 1010A)

This resolution chart is a five-bar chart that conforms to ANSI, ISO and NBS standards. Each of the five bars in a test element is 24 times as long as it is wide. The numeric value shown with each test element is the number of cycles/millimeter. See Figure 3.

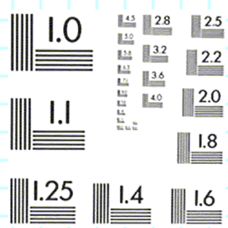


Figure 3. Microcopy Test Target.

(Test Target T10 from Applied Image, Rochester, NY)

The length of the bar for Microcopy test element 1.0 is 12 mm. Just like in the USAF 1951 Test Target, each test element in the Microcopy Test Target is a factor , $\frac{1}{\sqrt[6]{2}}$ = 0.89090, smaller than the previous element.

The Microcopy element 1.0, by definition, has a resolution of 1 cycle/millimeter. But this element corresponds to the USAF element Group 0, Element 1 (See Table 3), which has the same resolution. Since the same scaling factors are used by both targets, elements of the Microcopy target can be assigned to an equivalent USAF 1951 target element starting with elements Microcopy1.0 = USAF 1951 Group 0, Element 1. This mapping of equivalent test elements, along with size information, is summarized in Table 6:

			Line	Line	Equivalent USAF 1951 Target Element	
Index	Label	Cycles/mm	Length[mm]	Width[mm]	Series	Element
0	1.0	1.00000	12.00000	0.50000	0	1
1	1.1	1.12246	10.69078	0.44545	0	2
2	1.25	1.25992	9.52441	0.39685	0	3
3	1.4	1.41421	8.48528	0.35355	0	4
4	1.6	1.58740	7.55953	0.31498	0	5

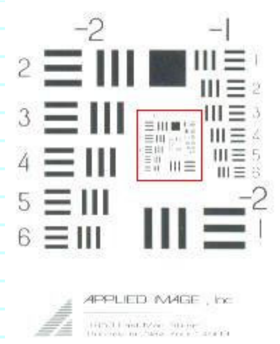
5	1.8	1.78180	6.73477	0.28062	0	6
6	2	2.00000	6.00000	0.25000	1	1
7	2.2	2.24492	5.34539	0.22272	1	2
8	2.5	2.51984	4.76220	0.19843	1	3
9	2.8	2.82843	4.24264	0.17678	1	4
10	3.2	3.17480	3.77976	0.15749	1	5
11	3.6	3.56359	3.36739	0.14031	1	6
12	4	4.00000	3.00000	0.12500	2	1
13	4.5	4.48985	2.67270	0.11136	2	2
14	5	5.03968	2.38110	0.09921	2	3
15	5.6	5.65685	2.12132	0.08839	2	4
16	6.3	6.34960	1.88988	0.07875	2	5
17	7.1	7.12719	1.68369	0.07015	2	6
18	8	8.00000	1.50000	0.06250	3	1
19	9	8.97970	1.33635	0.05568	3	2
20	10	10.07937	1.19055	0.04961	3	3
21	11	11.31371	1.06066	0.04419	3	4
22	12.5	12.69921	0.94494	0.03937	3	5
23	14	14.25438	0.84185	0.03508	3	6
24	16	16.00000	0.75000	0.03125	4	1
25	18	17.95939	0.66817	0.02784	4	2
		2^(Index/6)	12/Calc Cycles	Length/24		

Table 6. Microcopy Element Bar Lengths and Equivalent USAF 1951 Element.

In the above table, "Label" is the value printed on the test target element. The calculated cycles/mm is mathematically defined as $2^{index/6}$. The length and width are calculated as discussed above. The line length of the Microcopy element is 12/2.5 = 4.8 times the length of the corresponding USAF element.

Pixel Profiles

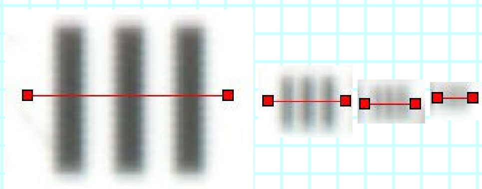
Let's use the program from Pixel Profile Lab Report to verify whether USAF 1951 test elements in an image from a PaperPort 5300 scanner can be resolved.



The test elements shown below are from the area enclosed in red in the above image. The image above was scanned at 75 dots/inch while the areas below were taken from an image scanned at 1200 dots/inch (both were scanned as color images even though the test target is in black and white).

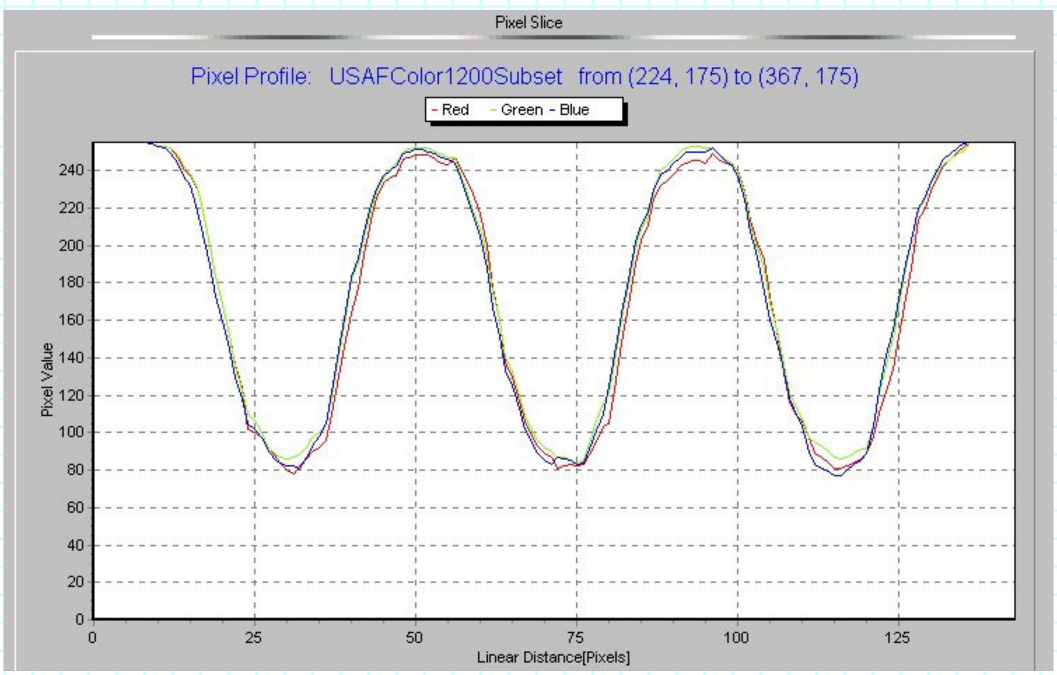
Group-Element in
USAF 1951 Test Chart

0-2 1-5 2-3 2-6

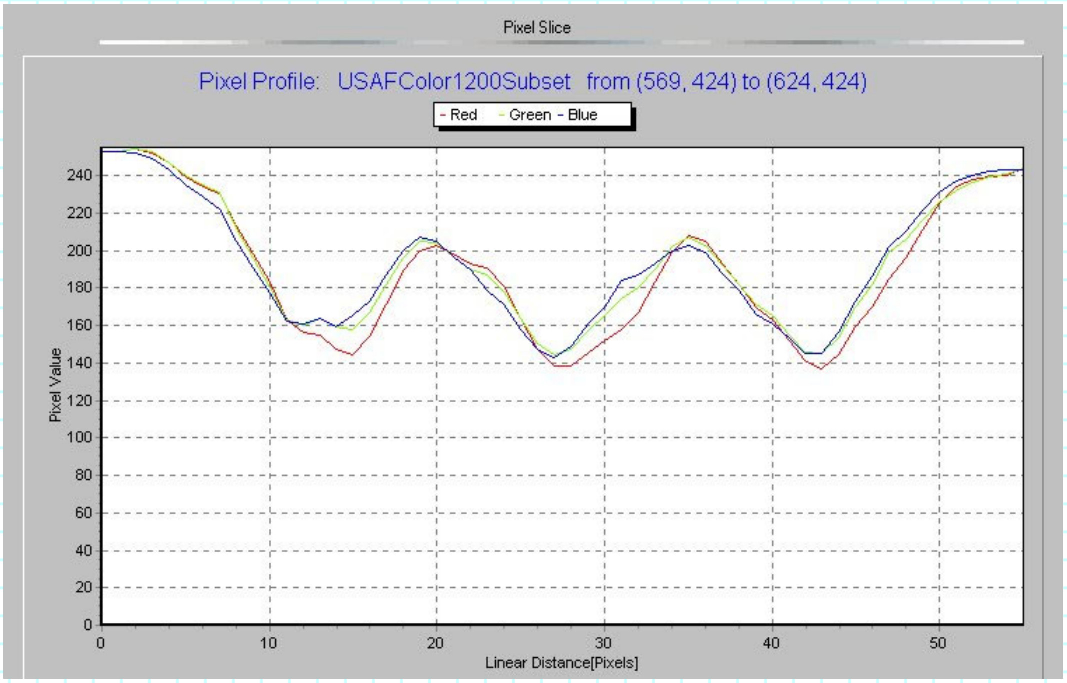


Graphs of the RGB intensities for the pixels along the red lines from above are shown below:

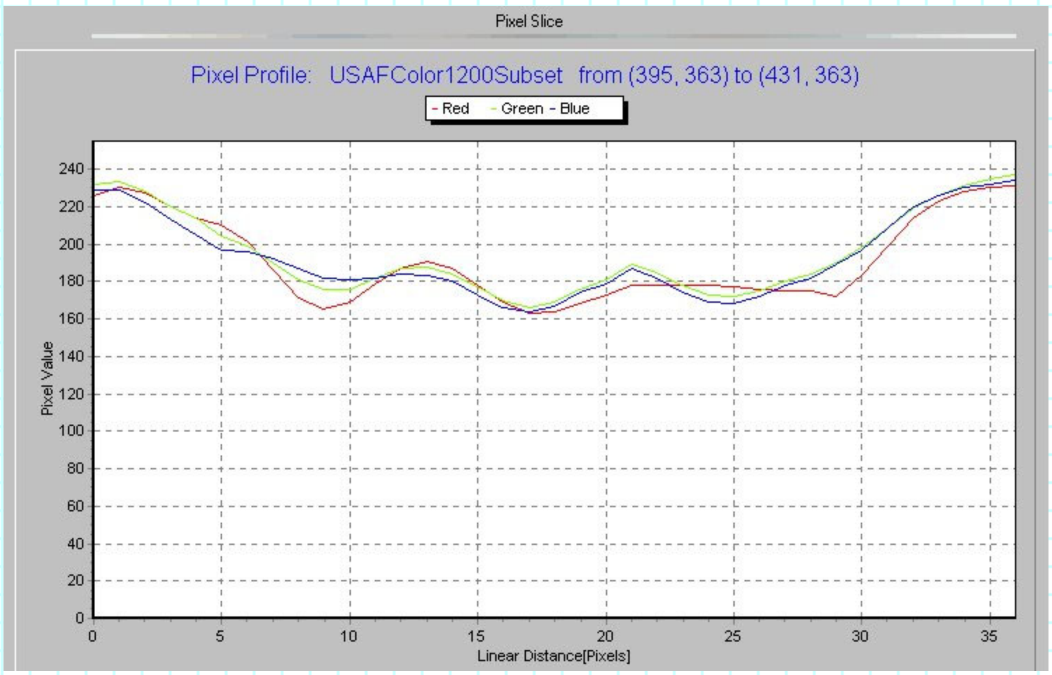
Test Element **0-2** Pixel Profile



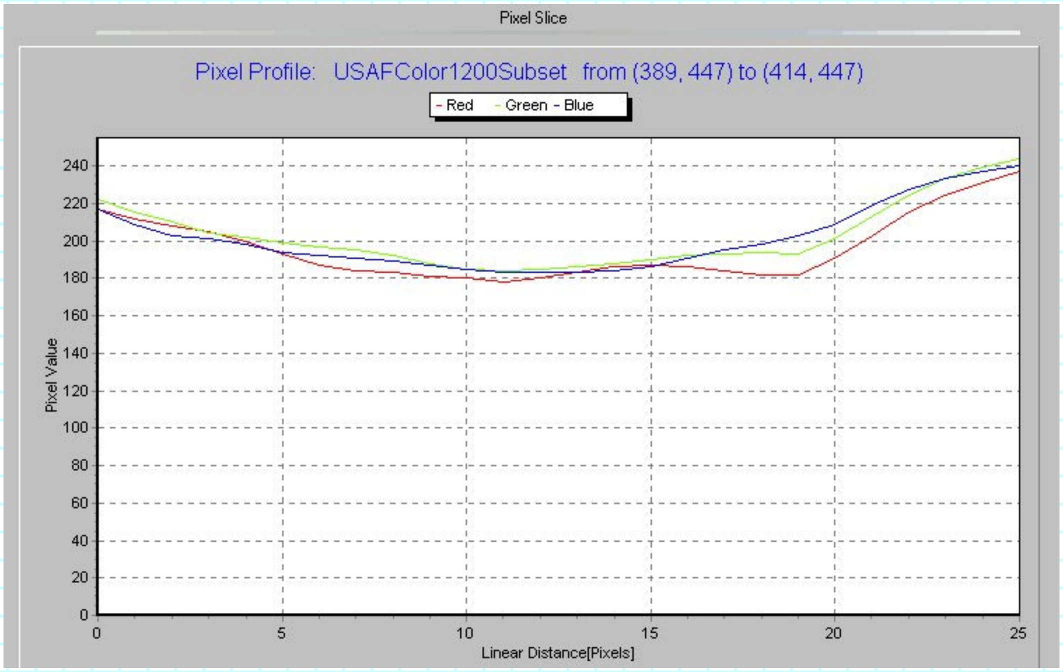
Test Element **1-5** Pixel Profile



Test Element **2-3** Pixel Profile



Test Element **2-6** Pixel Profile



Obviously, the lines in test element 2-6 cannot be resolved in the 1200 DPI image and are questionably resolvable in test element 2-3. Be aware that the definition of "resolve" is not standardized. Some want to see clearly distinguished lines, but others want only to recognize the direction of the lines. The use of a "pixel profile" helps standardize whether a target element can be resolved.

The article "Camera Users: Are You Afraid of the Dark?" in the May 1999 (pp. 183-189) *Photonics Spectra* describes using the USAF 1951 Test Target in various light levels.

Links

Kodak DC240 Test Images	www.imaging-resource.com/PRODS/DC240/240PICS.HTM
Imaging Databases and Test Targets	
Imaging Resource Test Suite	www.imaging-resource.com/TIPS/TESTS/TESTS.HTM
Modulation Transfer Function (MTF) Understanding image sharpness part 1: resolution and MTF curves in film and lenses www.normankoren.com/Tutorials/MTF.html Understanding image sharpness part 2: resolution and MTF curves in scanners and sharpening www.normankoren.com/Tutorials/MTF2.html	

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